Bond Illiquidity and Excess Volatility

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Abstract

We find that the empirical volatilities of corporate bond and CDS returns are higher than implied by equity return volatilities and the Merton model. This excess volatility may arise because structural models inadequately capture either fundamentals or illiquidity. Our evidence supports the latter explanation. We find little relation between excess volatility and measures of firm fundamentals and the volatility of firm fundamentals, but some relation with variables proxying for time-varying illiquidity. Consistent with an illiquidity explanation, firm-level bond portfolio returns, which average out bond-specific effects, significantly decrease excess volatility.

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1 Introduction

This paper studies excess volatility and its drivers in the corporate bond market. We examine the connection between the return volatilities of credit market securities, equities, and Treasuries using the Merton (1974) model with stochastic interest rates. To calculate model-implied corporate bond and CDS return volatilities, we use Treasury bond and equity return volatilities as inputs in the Merton model. Using monthly returns calculated from transaction size-weighted prices, the mean empirical bond volatility is 6.86% and the mean model-implied volatility is 4.66%, implying an excess volatility of 2.19 percentage points. In the CDS market, empirical volatilities exceed model-implied volatilities by an average of 1.92 and 2.84 percentage points when daily and monthly returns are used, respectively.

There are two primary explanations for excess volatility: an inability of the Merton model to properly account for the dynamics of firm-level fundamentals in relating equity and credit markets or volatility due to illiquidity. These two explanations have very different implications for research in credit risk models. The former guides research in the direction of different credit risk mechanisms and firm fundamentals whereas the latter guides research in the direction of frictions that structural models are not designed to capture. Distinguishing between these two explanations is important for understanding the practical applicability of structural models of default.

To distinguish between the fundamentals and illiquidity explanations, we first regress excess volatility on firm-level characteristics and proxies for bond illiquidity. Our firm-level characteristics include accounting-based variables that have been shown to predict default such as interest coverage and profitability. In addition, we follow previous research and include the volatilities of cash flows, earnings, leverage, and sales, as a linear relation between returns and characteristics implies a relation between return volatilities and the volatilities of characteristics. None of the fundamental variables consistently explains excess bond volatility.

We next consider the relation between excess volatility and a number of bond illiquidity proxies including quoted bid-ask spreads, zero trading days, and the Amihud (2002) measure. Importantly, we also consider time-varying illiquidity as a constant level of illiquidity does not necessarily imply that there will be excess volatility. We find that excess volatility is most closely related to proxies for time-varying bond illiquidity. In particular, a one standard deviation change in the volatility of the Amihud measure is associated with an additional 50 basis points of excess volatility, consistent with the variation of illiquidity being an important driver of excess volatility.

To further determine the relative contributions of fundamentals and illiquidity to excess volatility, we consider portfolios of bonds issued by the same firm. Taking all of the bonds issued by a firm and forming portfolios, we can largely diversify away the volatility of returns due to the bond-specific components of illiquidity and noise. However, such portfolios will not diversify away shared firm fundamentals. Using firm-level bond portfolios, we see a markedly reduced excess volatility of 1.22 percentage points with a t-stat of 1.80. If we further restrict our sample to firms with at least five bonds, so that the diversification of bond-specific factors is greater, excess volatility drops further to 57 basis points with a t-stat of 0.89. Thus, our results show that excess volatility is largely driven by bond-specific effects and are supportive of an illiquidity explanation for excess volatility rather than an explanation based on firm-level fundamentals.

We also consider the time series dynamics of CDS and equity return volatilities. As the main input in calculating model-implied volatility is equity volatility, a comparison of empirical and model CDS return volatilities is implicitly a comparison of the relative volatilities of returns in the CDS and equity markets. We find strong co-movement between empirical and model-implied CDS volatilities. The evidence for excess volatility is weaker during the Financial Crisis as equity volatility was particularly high during this period, contributing to high model-implied CDS return volatilities. One of our calibrations generates a statistically insignificant excess volatility of 32 basis points for the second half of 2008 and all of 2009. While illiquidity was high in the corporate bond market during the Financial Crisis, evidence on the illiquidity of the CDS market during the crisis is less clear. In addition, a high level of illiquidity does not necessarily imply high excess volatility. Feldhutter (2012) finds persistent price pressures during the crisis suggesting that while illiquidity was high during the crisis, it was not necessarily volatile. With highly time-varying fundamentals and persistent illiquidity in the CDS market, at least in the short-run, it seems plausible that empirical volatilities during this period of time largely reflected fundamentals. Furthermore, we find that changes in the Conference Board composite leading and coincident economic indicators, which measure aggregate economic conditions, are positively related to excess volatility, consistent with model volatilities being particularly low and excess volatilities being particularly high during periods of good economic conditions.

Finally, it is important to note that the excess volatility of credit market securities that we find is not a simple product of microstructure noise or bid-ask bounce. As Bao, Pan, and Wang (2011) show, the autocovariance of the corporate bond market is quite high and negative, symptomatic of a large effective bid-ask spread. At short horizons, empirical volatilities that use transaction prices are dominated by volatilities from this spread.[1] For this reason, we use transaction size-weighted prices and focus on monthly returns when calculating the volatility of corporate bond returns. Similarly, we focus on quoted mid prices when calculating CDS returns.

Our paper is most closely tied to the literature on structural models of default. Huang and Huang (2003) find that when matched to historical default probabilities, a number of structural models with different mechanisms underpredict corporate bond yield spreads (the credit spread puzzle).[2] Much of the literature that has followed[3] has attempted to explain the credit spread puzzle either through different model dynamics or through an illiquidity component. Our paper adds to this debate by examining the fit of structural models using volatilities and quantifying a disconnect between empirically observed and structural model-based bond volatility. We also find evidence that is largely consistent with illiquidity rather

[1] In an earlier draft of this paper, we found that mean annualized empirical volatilities were 21.77% when daily returns from transaction prices were used as compared to 8.10% when monthly returns were used.

[2] Jones, Mason, and Rosenfeld (1984) and Eom, Helwege, and Huang (2004) also find that structural models of default are unable to match the magnitudes of credit spreads.

[3] See Huang and Huang (2012) for a survey.

than fundamentals explaining the disconnect between empirical and model bond volatilities. In a related paper, Schaefer and Strebulaev (2008) find that the Merton model produces reasonable hedge ratios to explain contemporaneous equity and corporate bond returns.[4] Our results are largely consistent with the Merton model providing reasonable estimates of the relative fundamentals in the equity and corporate bond markets on average.

The rest of the paper is organized as follows. Section 2 outlines the empirical specification. Section 3 summarizes the data and the sample. Section 4 documents the volatility estimates. Section 5 examines some possible explanations for the differences between empirical and model volatilities. Section 6 concludes.

2 Empirical Specification

An important challenge for our analysis is determining a model-implied bond volatility to compare to empirically estimated bond volatility. To do this, we start with a two-factor model. The firm value process is a Geometric Brownian Motion under Q.

$$\frac{dV_t}{V_t} = (r_t - \delta)\, dt + \sigma_v\, dW_t^Q\,, \tag{1}$$

where W^Q is a standard Brownian motion, and where the payout rate δ and the asset volatility σ_v are assumed to be constant.

The interest rate, r_t is assumed to follow a Vasicek (1977) process

$$dr_t = \kappa\,(\theta - r_t)\ dt + \sigma_r\, dZ_t^Q\,, \tag{2}$$

where Z^Q is a standard Brownian motion independent of W^Q,[5] and where the mean-reversion

[4] Collin-Dufresne, Goldstein, and Martin (2001) use a reduced-form framework, finding that macroeconomic factors explain only 20-30% of changes in credit spreads. Schaefer and Strebulaev (2008) find R^2's on the order of 50% in return-based regressions. Thus, even though Merton model hedge ratios are of the right size to approximate the relative returns of debt and equity, there is still some part of debt returns that remains unexplained.

[5] Analysis in the Internet Appendix shows that the assumption of uncorrelated Brownian Motions has little effect on our main conclusions.

rate κ, long-run mean θ and the diffusion coefficient σ_r are assumed to be constant.

From this two factor process, we can write the relation between bond volatility and asset and interest rate volatilities as

$$\left(\sigma_D^{\text{Model}}\right)^2 = \left(\frac{\partial \ln B_t}{\partial \ln V_t}\right)^2 \sigma_v^2 + \left(\frac{\partial \ln B_t}{\partial r_t}\right)^2 \sigma_r^2 \, . \tag{3}$$

In fact, equation (3) holds for any arbitrary security that is a function of the two state variables, the firm value and the risk-free rate. The primary challenges in applying equation (3) are (a) to specify a functional form for bond value in order to calculate the partial derivatives and (b) to determine values for σ_v and σ_r. For bond value, we use an extended Merton model similar to Eom, Helwege, and Huang (2004). Consider a τ-year bond paying semi-annual coupons with an annual rate of c. Assuming a face value of \$1, the time-t price of the bond is

$$\begin{aligned} B_t = & \sum_{i=1}^{2\tau} \frac{c}{2} E_t^Q \left[\exp\left(- \int_t^{t+i/2} r_s ds \right) \mathbf{1}_{\{V_{t+i/2} > K\}} \right] + E_t^Q \left[\exp\left(- \int_t^{T} r_s ds \right) \mathbf{1}_{\{V_T > K\}} \right] \\ & + \sum_{i=1}^{2\tau} \mathcal{R} \left\{ E_t^Q \left[\exp\left(- \int_t^{t+i/2} r_s ds \right) \mathbf{1}_{\{V_{t+(i-1)/2} > K\}} \right] - E_t^Q \left[\exp\left(- \int_t^{t+i/2} r_s ds \right) \mathbf{1}_{\{V_{t+i/2} > K\}} \right] \right\} \end{aligned} \tag{4}$$

where $\mathcal{R}$ is the risk-neutral expected recovery rate of the bond upon default.[6] The first two terms in equation (4) collect the coupon and the principal payments, taking into account the probabilities of survival up to each payment. The third term collects the recovery of the bond taking into account the probability of default happening exactly within each six-month period. The solutions to these expectations and the full bond pricing formula are given in Appendix B.3.

To gain some intuition for the bond pricing model used, consider a τ-year zero-coupon bond. The partial derivatives for a zero-coupon bond simplify to

$$\frac{\partial \ln B_t}{\partial \ln V_t} = \frac{n(d_2)\,(1-\mathcal{R})}{N(d_2) + (1 - N(d_2))\,\mathcal{R}} \frac{1}{\sqrt{\Sigma}} \quad \text{and} \quad \frac{\partial \ln B_t}{\partial r_t} = b(\tau) \left(1 - \frac{\partial \ln B_t}{\partial \ln V_t} \right) ,$$

[6]We use a recovery of 50%. Huang and Huang (2003) use a recovery rate of 51.31%.

where $n(\cdot)$ is the probability distribution function of a standard normal and $-b(\tau)$ is the modified duration of a Treasury bond from the Vasicek model. As expected, with full recovery upon default, $\mathcal{R} = 1$, the bond is equivalent to a Treasury bond, its asset-sensitivity is zero, and its Treasury-sensitivity becomes $b(\tau)$. The asset-sensitivity becomes more important with increasing loss given default, $1-\mathcal{R}$, as well as with increasing firm leverage K/V. From this example, we can also see the importance of allowing for a stochastic risk-free rate, as the Treasury volatility is an important component in the defaultable bond volatility. In contrast, securities such as CDS and floating rate bonds are less sensitive to Treasury volatility due to low interest rate sensitivity.

Determining σ_v and σ_r requires applying equation (3), but for different securities. To obtain σ_r, we match the observed volatility of 7-year Treasury bond returns.[7] Full details of the implementation are provided in Appendix A, but the main calculation is to plug empirical Treasury volatility into equation (3) as σ_D^{Model} to determine the value of σ_r.[8] To obtain σ_v, we make use of the relation between equity, asset, and interest rate volatilities

$$\sigma_E^2 = \left(\frac{\partial \ln E_t}{\partial \ln V_t}\right)^2 \sigma_v^2 + \left(\frac{\partial \ln E_t}{\partial r_t}\right)^2 \sigma_r^2 \,. \tag{5}$$

As equity value, E_t is a function of σ_v, the value of σ_v cannot be directly calculated and is instead solved for such that equation (5) holds. Conceptually, this is similar to calculating the implied volatility in the Black-Scholes model. Full details of the calculation of the necessary firm-level parameters and the functional form of E_t are provided in Appendix B.[9]

[7] 7-year Treasury bonds are used as the average maturity of the corporate bonds in our sample is close to seven years.

[8] See equation 8 in Appendix A.

[9] In Appendix D, we consider an alternative method of calculating σ_v that disentangles the long-run asset volatility that determines $\frac{\partial \ln E_t}{\partial \ln V_t}$ and the short-run realized asset volatility which appears as σ_v in equation (5). Further methods for calculating asset volatility and additional structural models are discussed in the Internet Appendix.

3 Data

3.1 Data Sources

The bond pricing data for this paper are obtained from FINRA's TRACE (Transaction Reporting and Compliance Engine). FINRA is responsible for operating the reporting and dissemination facility for over-the-counter corporate trades. Trade reports are time-stamped and include information on the clean price and par value traded, although the par value traded is top-coded at $1 million for speculative grade bonds and at $5 million for investment grade bonds. The bond data is matched to Mergent FISD to obtain bond characteristics.

The cross-sections of bonds in our sample vary with the expansion of coverage by TRACE. On July 1, 2002, the NASD began Phase I of bond transaction reporting, requiring that transaction information be disseminated for investment grade securities with an initial issue of $1 billion or greater. At the end of 2002, the NASD was disseminating information on approximately 520 bonds. Phase II, implemented on April 14, 2003, expanded reporting requirements, bringing the number of bonds to approximately 4,650. Phase III, implemented on February 7, 2005, required reporting on approximately 99% of all public transactions.

The CDS data for this paper are obtained from Datastream. Prior to 2007, Datastream's sole source of CDS data was CMA Datavision. Mayordomo, Pena, and Schwartz (2010) find that the CMA database leads the price discovery process in comparison with a number of CDS databases including Markit. In 2007, Datastream began reporting CDS data from Thomson Reuters and eventually ceased its coverage of the CMA data in September 2010. Given the evidence that the CMA data is of high quality and the uncertainty regarding the quality of the Thomson data, we focus on the CMA data, which covers the period from January 2004 to September 2010,[10] and use 5-year credit default swaps as they are the most liquid. Over this period of time, the CMA data in Datastream covers 695 names for 5-year senior CDS, though many names are only covered for a short subset of the period. This data

[10]In the Internet Appendix, we also supplement our data with CMA New York data for the rest of 2010, obtained from Bloomberg.

consists of bid, ask, and mid consensus prices.

The remaining data are from standard data sources. CRSP is used for stock market data and Compustat for firm-level Accounting data. We use the U.S. Treasury's Constant Maturity Treasury (CMT) series for interest rates.

3.2 Sample Description

We use transaction-level data from TRACE to construct bond return volatilities for non-financial firms. First, we construct monthly bond returns as follows. For a bond in month t, we take all trades from the 21st of the month and later. We calculate the clean price for the end of the month as the transaction size-weighted average of these trades.[11] Returns are then calculated as:

$$R_t = \ln\left(\frac{P_t + AI_t + C_t}{P_{t-1} + AI_{t-1}}\right)$$

where P_t is the transaction size-weighted average clean price, AI_t is the accrued interest, and C_t is the coupon paid in month t. Bond-level information is obtained from FISD for coupon rates and maturities. Accrued interest is calculated using the standard 30/360 convention and returns are only calculated for month t if we have a transaction price for both month t and month $t-1$.[12] We do not calculate daily returns for the corporate bond sample. At short horizons, small components of the bid-ask spread that are not fully eliminated can significantly contribute to volatility. In the CDS sample, we consider both daily and monthly returns, using consensus mid prices. For each bond-year and CDS-year, we then calculate the volatility of monthly returns in a year if there are at least 10 returns available and annualize.[13]

[11] Bessembinder, Kahle, Maxwell, and Xu (2009) recommend calculating prices as the transaction size-weighted average of prices. This minimizes the effects of bid-ask spreads in prices. As shown in Edwards, Harris, and Piwowar (2007) and Bao, Pan, and Wang (2011), these effects are largest for small trades. Our choice of considering trades on the 21st or later is based on obtaining a balance between prices that reflect month-end prices and maintaining a reasonable number of trades to calculate average prices.

[12] An alternative treatment would be to use the last trade in a month regardless of what day the trade occurred and to treat clean prices as unchanged if no trades occurred. However, this would lead to returns in the bond market that do not necessarily reflect changes in asset value during the month, breaking the link between equities and corporate bonds.

[13] In the Internet Appendix, we consider using rolling window volatility estimates.

For each CDS-month, we calculate the volatility of daily returns and annualize.[14]

Table 1 summarizes the corporate bonds in our sample and Table 2 summarizes the firms corresponding to the corporate bonds and CDS in our sample. As Panel A of Table 1 shows, there are 1,021 distinct bonds in our sample and 2,883 bond-years. Similar to most studies using TRACE, our sample is limited simply because many bonds do not trade frequently. Imposing the restriction that prices must be from the 21st of the month or later and that there must be at least 10 returns in a year to calculate a volatility, there are close to 28,000 bond-years and 10,000 distinct bonds. The sample is further reduced to about 24,000 observations when we impose the restriction that the bond-year must match to ordinary equity in CRSP. About one-third of the remaining observations are Financials, which are dropped. Additional filters that decrease the sample size include filtering out putables, convertibles, and callables along with dropping bonds issued by firms with insufficient information in Compustat. The primary reason for the decrease in sample size at this stage is due to the fact that most corporate bonds, particularly those issued by non-financials, are callable.[15]

Due to the fact that large issues tend to trade more frequently, the bonds in our sample are larger issues than the typical bonds in FISD, with an average face value of $585mm compared to $184mm for the full FISD sample. The bonds in our sample also tend to be older, but are of similar ratings on average (7=A3). The average number of trades in a year for the bonds in our sample is approximately 1,500, which is frequent in the corporate bond market. By contrast, Edwards, Harris, and Piwowar (2007) report that the average bond in their sample trades 2.4 times a day and the median bond 1.1 times a day.

In Table 2, we present summary statistics for the firms represented in our corporate bond (Panel A) and CDS (Panel B) samples. There are 735 firm-years in our corporate bond sample or an average of 92 firms per year. These firms are relatively large, averaging $40 billion in equity market capitalization and representing an average of $3.7 trillion in

[14]The full procedure for calculating returns and volatilities for CDS is described in Appendix C.

[15]Note that the number of bonds in Dick-Nielsen, Feldhutter, and Lando (2012) is 2,224 (Table 2 of their paper) and the number of bonds in Bao, Pan, and Wang (2011) is 1,035. Both of these papers include Financials, but also have different filtering criteria due to their different research questions.

total equity market capitalization and $4.3 trillion in total book assets per year. The firms represented in our CDS sample are broader, with an average of 303 firms per year. These firms are also large, with an average market capitalization of $22.59 billion. Thus, the firms in the CDS sample cover an average of $6.8 trillion in total equity market capitalization each year. As a comparison, the total market capitalization for non-financial ordinary shares in CRSP was $9.3 trillion in 2008. In addition to being large, the average firm in our sample is healthy as the average firm is profitable and has a coverage ratio close to 10.

4 Volatility Estimates

4.1 Empirical Bond Return Volatility $\hat{\sigma}_D$

In the first column of Table 3, we report the empirical bond and CDS volatilities. Empirical bond volatilities using monthly bond returns are presented in Panel A. We find that the average annualized volatility for the full sample is 6.86% and that there is an interesting pattern to the average bond volatility each year. From 2003 to 2007, the average bond volatility decreases each year, despite the fact that FINRA introduced coverage of additional issues, which were believed to be less liquid. During the Financial Crisis in 2008 and 2009, empirical bond volatility spikes, before returning to levels closer to those observed pre-crisis in 2010. There are two sources to this pattern. First, we show in Appendix A that Treasury bond volatility decreased during the early part of our sample. Second, volatility in markets, including the equity market, increased during the Financial Crisis. As corporate bonds and equities are both sensitive to underlying firm conditions, we would typically expect corporate bond volatilities to be high when equity volatilities are high.

To better understand the empirically estimated bond volatilities, we sort bonds into quartiles each year by bond- or firm-level characteristics and report the average contemporaneous empirical bond volatility in Panel A of Table 4. We find that less liquid bonds (lower amount outstanding, greater proportion of zero trading days, higher Amihud measure, and higher

Implied Round-trip Cost), poorer rated bonds, and longer maturity bonds tend to have higher empirical volatilities. Firm characteristics are also important as firms with higher equity volatility, K/V, and payout ratios also tend to have higher volatilities. These results are generally robust to both the first and second half of our sample, though the spread in empirical bond volatility across quartiles tends to be larger in the second half of the sample.

We report estimates of empirical CDS volatility in Panels B (daily returns used to calculate volatility each month) and C (monthly returns used to calculate volatility each year) of Table 3. We find that the average empirical volatilities are 4.87% and 5.56%, respectively. Both estimates are lower than in the corporate bond market, as CDS are much less sensitive to interest rates. Similar to corporate bonds, we find that CDS volatility spikes during the Financial Crisis.

In the bottom half of Panel A in Table 4, we examine the relation between CDS volatility (calculated using monthly returns) and characteristics by performing similar year-by-year sorts as for corporate bonds. Many of our conclusions are similar to those for corporate bonds. Lower credit quality and more illiquid CDS have higher average empirical volatilities. The results hold for both the first and second half of our sample, though the spread is again wider during the second half.

4.2 Equity Return Volatility $\hat{\sigma}_E$

The equity return volatility, from which the asset volatility of a firm can be backed out, is one key input to the structural model. Equity volatility is calculated each year using monthly returns when matched to bond or CDS volatilities from monthly returns. When matched to the sample using CDS volatilities calculated each month using daily returns, we calculate equity volatilities each month using daily returns. In Table 3, we summarize equity volatility for the issuers of corporate bonds and reference entities for CDS in our sample. For the firms represented in our corporate bond sample, we find a similar pattern of equity volatility as we did for bond volatility in Section 4.1. Just prior to the crisis, equity volatilities were low and during the crisis, they spiked. The mean of equity volatility for the full corporate bond sample is 27.59%, as compared to 6.86% for corporate bond volatility. However, without implementing a structural model, it is difficult to determine if these relative magnitudes are reasonable.

For the firms in our CDS sample, we also see a similar pattern for equity volatility over time, as equity volatility is particularly high around the Financial Crisis. Generally, the equity volatility for firms in our CDS sample is slightly higher on average as compared to firms in our corporate bond sample at 34.55% and 31.46% when daily and monthly returns are used, respectively. Given that our CDS sample includes a broader set of firms, many of which are smaller, this seems reasonable.

4.3 Model-Implied Volatilities

For each firm in our sample, we back out its asset volatility, σ_v^{Merton} via equation (5). Details of the calculation are described in Section 2 and Appendix B, but the basic methodology is that for each firm i in year t, we use leverage K/V, payout ratio δ, firm T, and interest rate parameters in equation (5) and find the asset volatility, σ_v^{Merton}, such that the model equity volatility given in equation (5) matches empirically observed equity volatility for the corresponding firm in year t. We note that there are some cases where asset volatility cannot be backed out from equation (5). For highly levered firms in our sample, even a low asset volatility implies a high equity volatility. This is due to the fact that for highly levered firms, a low asset volatility implies a very low value of equity. With a very low value of equity, both $\partial \ln E / \partial \ln V$ and $\partial \ln E / \partial r$ are large. If the empirically observed equity volatility is low, there is no asset volatility that can satisfy equation (5). In about 18% of our initial bond-year sample and 5% of our CDS sample, this occurs.[16] An alternative method for implementing the Merton model that we consider in Appendix D mitigates this problem.

With asset volatility σ_v^{Merton} estimated, we can then calculate model-implied bond volatil-

[16]Such observations are not included in our main sample and are not included in the summary statistics or volatilities reported in Tables 1 to 7.

ity, σ_D^{Merton} following the methodology described in Section 2. In the last column, of Table 3, we summarize our model-implied bond volatility estimates. For our corporate bond, CDS using daily returns, and CDS using monthly returns samples, the mean model-implied volatilities are 4.66%, 2.95%, and 2.72%, respectively. As equity volatility is one of our main inputs into the calculation of asset volatility and then model bond and CDS volatility, our model-implied bond and CDS volatilities exhibit similar patterns to equity volatility. They are lower during the early part of our sample, but show a pronounced increase during the Financial Crisis. However, we also note that the mean model-implied bond and CDS volatilities are smaller than the empirical bond and CDS volatilities also reported in Table 3.[17]

We further examine the characteristics of our model-implied volatilities in Panel B of Table 4. Sorting on different security- and firm-level characteristics each year as in Sections 4.1 and 4.2, we find that the model-implied volatilities appear to be related to both variables that proxy for risk and also liquidity variables. While the former is predicted by the model, the latter result is suggestive of a correlation between liquidity variables and fundamental firm characteristics. Longer maturity bonds, bonds issued by firms with poorer ratings, and bonds issued by firms with higher equity volatility have higher model-implied bond volatility. However, we note that the relation between model volatility and rating and equity volatility is largely driven by the second half of our sample. The explanation for this lies in the fact that model-implied bond volatility is not monotonic in asset volatility and credit risk. As noted in Appendix B.4, a riskier bond has a higher sensitivity to asset value, but a lower sensitivity to interest rates than a very safe bond. At low levels of riskiness, the increase in model-implied volatility from the increase in sensitivity to asset value is more than offset by the decrease in model-implied volatility from the decrease in interest rate sensitivity. At high levels of riskiness, which are more common in the second half of the period, the higher sensitivity to asset value dominates and model-implied volatilities are particularly high for the fourth quartile of rating and equity volatility. By contrast, the model-implied

[17]In a related paper, Huang and Zhou (2008) find that structural models underestimate equity return volatility for investment grade issuers.

CDS volatility is higher for firms with poorer credit ratings, higher CDS spreads, and greater equity volatility for both halves of our sample. This is due to the fact that CDS have little sensitivity to interest rates. Thus, for a CDS, the increase in model-implied volatility from an increase in sensitivity to asset value dominates the decrease in model-implied volatility form a decrease in sensitivity to interest rates even at low levels of credit risk.

4.4 Empirical vs. Model Return Volatilities

In Tables 5 and 6, we report the differences between empirically estimated and model implied volatilities for corporate bonds and CDS. For corporate bonds, the excess volatility is 2.19% on average, with a t-stat of 2.74.[18] The median excess volatility is 0.58% and the 25th percentile is 0.18%. As the distribution of excess volatility is positively skewed, we also winsorize excess volatility to decrease the effects of extreme observations. When we winsorize 1% of each tail, we find a mean excess volatility of 2.02% with a t-stat of 2.92. At 2.5% winsorization, we find a mean of 1.95% and a t-stat of 3.04. Thus, while winsorization decreases the mean excess volatility since the data is positively skewed, it also decreases the standard errors, making the results more statistically significant. In Table 5, we also find that excess volatility is more severe for bonds with poorer ratings and also longer maturity bonds. However, whether this shows that the model fails to capture fundamentals is unclear as longer maturity bonds and bonds with poorer ratings also tend to be less liquid.

We also consider callable bonds in Table 5. For all of the other analysis, we have omitted callable bonds because the Merton model does not deal with callability. However, as most bonds issued by non-financials are callable (approximately 76% in our sample), we report results for callable bonds here in an effort to provide some guidance as to whether our results generalize to the broader bond market.[19] Callable bonds have an average excess volatility of 2.71% and a t-stat of 2.29. Thus, our results suggest that callable bonds also exhibit excess

[18]Standard errors are clusterd by firm and time as discussed by Cameron, Gelbach, and Miller (2011). In addition, bootstrapped standard errors are discussed in the Internet Appendix.

[19]In calculating model bond volatilities, we treat callable bonds as if they are straight bonds. Thus, the results here are only suggestive.

volatility.

Excess CDS volatilities are reported in Table 6 and our conclusions are similar. When daily CDS returns are used to calculate volatilities each month, the mean excess volatility is 1.92% (t = 7.23). When monthly CDS returns are used, the mean excess volatility is 2.84% (t = 3.77). The distribution of excess volatility is positively skewed, as with corporate bonds and thus, we also calculate the mean excess volatility with 1% and 2.5% of each tail winsorized. For daily returns, we find excess volatility of 1.25% (t = 8.50) and 1.02% (t = 7.19) for the two levels of winsorization. For monthly returns, we find excess volatility of 2.54% (t = 4.22) and 2.02% (t = 6.29) for the two levels of winsorization. Thus, while excess volatility for CDS is positively skewed, it does not appear to be driven solely by the tails.

An alternative way to gauge the performance of the Merton model in matching the empirical bond volatility is to use the ratio of the empirical bond volatility that can be explained by the Merton model. Statistical tests on the ratio of model-to-empirical volatilities can be tricky and unreliable as the ratio is bounded below by 0 and is unbounded above. In particular, cases where empirical volatility is very low may lead to ratios far greater than 1. Just having a small percentage of such cases can lead to average ratios that are deceptively close to or even greater than 1. Thus, we instead focus on the ratio of the average model volatility to the average empirical volatility. In Tables 5 and 6, both averages are reported to allow such a comparison. The ratio of average model volatility to average empirical volatility is 0.68 for corporate bonds and 0.61 and 0.49 for CDS using daily and monthly returns, respectively.

Finally, we consider an overlapping sample for corporate bonds and CDS. For most of our analysis, we have maintained both a corporate bond sample and CDS sample in an effort to maintain as comprehensive a sample as possible. In Table 7, we restrict the corporate bond and CDS (using monthly returns) samples to firm-years for which we have both a CDS and at least one bond in order to facilitate comparison. We find that for this overlapping sample, the mean excess volatility for corporate bonds is 2.72% and the mean excess volatility for CDS is 2.52%. Overall, it appears that the volatility in the credit market is higher than can be explained by equity markets and the Merton model. The source of this difference is the focus of the following section.

5 Explaining Excess Volatility

To examine the sources of excess volatility, it is useful to use a linear factor model for intuition

$$r_{b,t} = f_{b,t} + liq_{b,t} + e_{b,t} \tag{6}$$

where $f_{b,t}$ is a fundamental return term, $liq_{b,t}$ is a return due to liquidity, and $e_{b,t}$ is a random noise term. The natural explanations for excess volatility are the Merton model being unable to capture volatility from firm-level fundamentals or a combination of volatility due to illiquidity and noise.

We conduct analyses to both better understand the fit of the Merton model in matching corporate bond and equity volatilities and to shed light as to whether the primary source of excess volatility is a mismatch in the dynamics of fundamentals or volatility due to illiquidity. First, we examine the relation between excess volatility and variables that proxy for both the level and the volatility of firm-level fundamentals and of bond-level illiquidity. Second, as bonds issued by the same firm share the same underlying firm-level fundamentals, but not the same liquidity and noise, this implies that a well-diversified portfolio of bonds issued by the same firm will reflect the volatility from firm-level fundamentals without the volatility due to bond-specific illiquidity and noise. If excess volatility is due to bond-specific effects, there should be no excess volatility when empirical volatilities are calculated using portfolio returns.

Finally, we focus on monthly CDS volatilities calculated using daily returns and examine volatility in the time series. Gauging the time series fit of the Merton model provides some evidence as to the economic environment when the model performs better. Whether the model performs better or worse during periods of crisis is an empirical question as periods of crisis are related to large changes in fundamentals and high levels of illiquidity. It is the time-variation of illiquidity that is directly linked to excess volatility rather than the level of illiquidity, and it is unclear whether the volatility of fundamentals or the volatility of illiquidity was the dominant effect in the CDS market during the crisis.

5.1 Volatility, Firm-Level Characteristics and Liquidity

As a first pass in determining whether excess volatility in credit markets is due to fundamentals or illiquidity, we regress excess volatility on proxies for firm fundamentals and illiquidity. Importantly, we also include the volatility of fundamentals and illiquidity. We run panel regressions with time-fixed effects to account for the average levels in each period.

Variables Proxying for Fundamentals: We choose a number of accounting variables to proxy for firm conditions. EBIT/Assets, Sales/Assets, and Retained Earnings/Assets are motivated by their inclusion in the Altman (1968) Z-score to predict bankruptcy. Net Income/Assets and ln(Total Assets) are motivated by the logit default prediction model in Campbell, Hilscher, and Szilagyi (2007). Coverage Ratio is also included as it reflects the ability of a firm to cover interest expenses from earnings. In addition to these level variables, we also include a number of variables to proxy for volatility of fundamentals. We include the volatility of the ratio of cash flow to assets following Minton and Schrand (1999). Earnings volatility is included following Jayaraman (2008). As Collin-Dufresne and Goldstein (2001) note that time-varying leverage may be important in structural models, we include the volatility of leverage. Motivated by Sufi (2009), we also include sales volatility. All of the fundamental volatility variables are calculated using the previous five years of Compustat quarterly data.

Variables Proxying for Illiquidity: At the bond-level, we include controls for illiquidity. Following Houweling, Mentink, and Vorst (2005) we include age and amount outstanding of a bond. As in Chen, Lesmond, and Wei (2007), we use the bid-ask spread from Bloomberg, but we also add the standard deviation of the bid-ask spread to account for changing liquidity. We also include five proxies that are used in Dick-Nielsen, Feldhutter, and Lando (2012), Bond Zeros, the Amihud measure, the Implied Round-trip Cost (IRC), the volatility of the Amihud measure, and the volatility of IRC.[20] The latter four form the core liquidity measure used in Dick-Nielsen, Feldhutter, and Lando (2012).

Other Controls: For our corporate bond sample, we also include the Moody's rating as an additional control for firm conditions and the time to maturity as it was shown in Table 5 that excess volatility is most severe in magnitude for bonds with a longer time to maturity. For CDS, we include the CDS spread as an additional control for firm conditions, but cannot control for maturity as our sample is limited to 5-year CDS.

We report the results for corporate bonds in Table 8. Rating and time-to-maturity are included as controls for all specifications. Both are positive and significant across specifications. We find some evidence of a relation between excess volatility and proxies for illiquidity. The bid-ask spread, bond zeros, the implied round-trip measure, and the standard deviation of bid-ask spreads are all significantly positively related to excess volatility in some specifications. The volatility of the Amihud measure is statistically significant in all specifications. A one standard deviation change in the volatility of the Amihud measure is associated with a 50 basis point increase in excess volatility. As the previous literature has shown that the yield spreads of corporate bonds are related to proxies for illiquidity,[21] it is reasonable to expect that the volatility of illiquidity will be related to the volatility of illiquidity measures as changing levels of illiquidity should change bond prices. As the Merton model is not designed to capture bond illiquidity, model volatility is not directly linked to the volatility of bond illiquidity. Thus, the excess volatility of corporate bonds is linked to the volatility of illiquidity.

In contrast to the liquidity variables, we find few statistically significant relations between

[20] We do not include the γ measure from Bao, Pan, and Wang (2011) as many of our bonds do not trade frequently enough to precisely estimate γ.

[21] See Chen, Lesmond, and Wei (2007), Bao, Pan, and Wang (2011), Dick-Nielsen, Feldhutter, and Lando (2012), and Friewald, Jankowitsch, and Subrahmanyam (2012) among others.

excess volatility and proxies for firm-level fundamentals. Our results are consistent with liquidity contributing to excess volatility and fundamentals having little connection to excess volatility. However, we acknowledge that even after exploring ten proxies for firm-level fundamentals and the volatility of firm-level fundamentals, it remains possible that there are other proxies for firm fundamentals that are correlated with excess volatility.

In Table 9, we examine the relation between excess volatility in the CDS market and accounting variables, the CDS spread, and CDS liquidity variables. We consider CDS volatilities calculated from daily returns in both our base case and the case where we explicitly model realized short-run and constant long-run volatilities (Appendix D) in addition to CDS volatilities calculated from monthly returns. Similar to our corporate bond sample, we find most of accounting ratios to be insignificant. The two exceptions are EBIT/Assets, which are positive only if the base case with volatilities from daily returns are used and the log of total assets. Both results are surprising as this suggests that if anything, larger firms and firms with higher earnings have greater excess volatility. CDS with greater standard deviation of bid-ask spread have greater excess volatility, consistent with part of the excess volatility being associated with variation in illiquidity. This result is economically significant as a one basis point increase in the standard deviation of bid-ask spreads is associated with additional excess volatility on the order of 0.38 - 0.71 percentage points. The CDS spread is significantly positive in some, but not all specifications. Its importance is weaker when CDS liquidity variables are included, suggesting that perhaps the relation between credit quality and excess volatility may be related to the fact that securities with poorer credit ratings are also less liquid.

5.2 Bond Portfolios

In equation (6), bond returns are a function of fundamentals, illiquidity, and noise. Bonds issued by the same firm will share the same underlying firm-level fundamentals, but will have imperfectly correlated returns due to illiquidity and uncorrelated (by definition) noise. This suggests that if a portfolio of a firm's bonds is formed, the fundamental component cannot be diversified away, but much of the illiquidity and noise components can.[22] The implication for excess volatility is that if excess volatility is largely driven by the Merton model missing on firm-level fundamentals, the excess volatility effect should still exist using bond portfolios formed by firm.[23] However, if excess volatility is mostly due to illiquidity and noise effects, the magnitude of the effect should decline sharply when firm-level bond portfolios are used to calculate volatilities. The effect should be particularly large when the firm-level bond portfolios are formed using a large number of bonds.

For each firm-month, we average the returns of the bonds issued by the firm. We then calculate volatilities for these bond portfolios, $\hat{\sigma}_{D,firm}$ and define bond-level excess volatility as $\hat{\sigma}_{D,firm} - \sigma_D^{Merton}$, where σ_D^{Merton} is the model-implied bond volatility as calculated earlier. Excess volatility using firm-level bond portfolio returns is 1.22 percentage points with a t-stat of 1.80 as compared to the base result of 2.19 percentage points with a t-stat of 2.29. If we further restrict the sample to only firm-years which have at least 5 or 10 bonds, excess volatility using firm-level bond portfolio returns are 57 basis points (t = 0.89) and 42 basis points (t = 0.57), respectively. Thus, our results are consistent with the bond-specific component of illiquidity and noise being the major drivers of excess volatility.

5.3 Volatility in the Time-Series

We examine the performance of the Merton model in explaining volatility over time by primarily focusing on volatilities calculated from daily returns each month in the CDS market. Considering both the base case calibration as described in Section 4.3 and the short-run realized volatility as described in Appendix D, we calculate the mean of empirical and model volatilities each month and plot these averages in Figure 1. While Figure 1 shows that the

[22] Bonds need not share the same "beta" on firm-level fundamentals. The argument regarding diversification relies on a common firm-level component and a set of bonds that is representative of the distribution of "betas" across the set of a firm's bonds. It is also possible that bonds issued by a firm share a common illiquidity component. If this is an important driver of excess volatility, it would be more difficult to eliminate excess volatility by using portfolio returns.

[23] We use equal-weighted bond portfolios, but our results are similar if we use amount outstanding-weighted bond portfolios.

typical levels of model volatility are lower than empirical volatility, the time series correlations between the cross-sectional mean empirical and model volatilities are 0.9547 and 0.9533 for the base case and short-run realized calibrations, respectively. In addition, the model performs reasonably well around the Financial Crisis, particularly for the short-run realized volatility calibration case. It may seem surprising that the empirical volatility is not much higher than model volatility during the Financial Crisis, as this was a particularly illiquid period for credit markets. There are two explanations for this. First, during the Financial Crisis, the variance of fundamentals also increased. This is reflected in the increased equity volatilities during the crisis, which are in turn reflected in higher model volatilities. Second, price pressures during normal times are more likely to be transitory and contribute to empirical volatility estimates whereas price pressures during the Financial Crisis are more likely to be persistent due to persistent strong selling pressures as in Feldhutter (2012).[24]

We further examine the time-series relation between empirical and model volatilities by running panel regressions of firm-level empirical volatilities on model volatilities with bond or CDS fixed-effects. By including fixed-effects, we acknowledge that the level of empirical volatilities for most bonds (and CDS) are higher than those implied by the Merton model. This higher level may be due to a variety of issues including liquidity or fundamentals not captured by the model and is absorbed into the fixed-effects, allowing us to gauge whether empirical and model volatilities line-up over time when the level difference is accounted for.

The results in Table 10 suggest that at the CDS-level, empirical and model volatilities do co-move over time. When regressing empirical bond volatility on model bond volatility and bond fixed-effects, we find a coefficient of 1.14. Though a t-test of whether this coefficient equals 1 yield a t-statistic of 2.60 when standard errors are clustered by time, accounting for the small number of clusters by using a wild cluster bootstrap-t as in Cameron, Gelbach, and Miller (2008) suggests that the cutoff for a 5% rejection is 2.64. Running a similar regression using annual volatilities calculated from monthly CDS returns, we find a coefficient of 1.38

[24]In credit markets, bid-ask spreads were particularly large during the Financial Crisis and using transaction-level prices would lead to large volatility estimates. However, we avoid this issue by using consensus mid prices.

and a t-statistic of 1.52 when testing against a null of 1. When we use volatilities calculated from daily CDS returns and regress empirical volatilities on model volatilities with CDS fixed-effects, we find coefficients close to 0.8 regardless of whether the base methodology or the methodology in Appendix D is used. The within-group R^2 of our four specifications ranges from 33.67% to 46.28%, suggesting that a substantial proportion of the variation in empirical volatilities is explained by the model, even after de-meaning firm-by-firm. Overall, empirical bond and CDS volatilities tend to be higher than average exactly when model-implied volatilities are higher than average.

Next, we consider what might explain the variation of this difference in levels of empirical and model volatility across time. We use the excess volatility of CDS from daily returns as our regressand. As regressors, we include the changes to a number of macroeconomic variables and also market returns.

Aggregate Conditions: In incorporating macroeconomic variables, our goal is to determine whether the CDS in our sample have higher or lower than average excess volatility as market conditions change. For example, the VIX index is known as the "fear gauge" of the market. We aim to determine whether excess volatility is higher or lower in months when the fear gauge of the market increases. We also consider the University of Michigan Consumer Sentiment Index and the National Association of Purchasing Management's Business Conditions Index, both of which are based on surveys. The 3-month Repo rate, the 3-month LIBOR rate, and the term spread are included as existing evidence has shown that interest rates change with macroeconomic conditions. Furthermore, we include the credit spread, measured as the difference between the Baa and Aaa Barclays intermediate index yields, and a CDS index[25] as proxies for credit conditions. The Conference Board's composite leading and coincident economic indicators are composite indices of macroeconomic conditions and are included as in Huang and Kong (2003). The Bao, Pan, and Wang (2011) aggregate bond illiquidity index is included as an aggregate measure of bond market illiquidity. The S&P 500 return and Barclay's US Investment Grade Corporate Bond Index returns are included

[25]The CDS index is measured as the average five-year CDS spread of the firms in our CDS sample.

as measures of aggregate market performance over the course of the month.[26]

CDS- and Firm-level Variables: We consider the contemporaneous stock return of the underlying firm and the change in CDS spread during the month to proxy for changing firm-level financial conditions. We also control for changing liquidity conditions by using the change in CDS bid-ask spread and for the variation of liquidity conditions with the standard deviation of the bid-ask spread.

The results in Table 11 provide limited evidence of a relation between excess volatility and changes in individual macroeconomic proxies in the time-series. The primary economic conditions variables that are significantly related to excess volatility are changes in the aggregate economic indicators, the Conference Board's coincident and leading indicators. When macroeconomic conditions, as measured by these indicators, improve, excess volatility for CDS *increase*.[27] The interquartile ranges of changes in the leading and coincident indicators are 1.15 and 0.55, respectively. This corresponds to differences in excess volatility of roughly 0.47 and 0.62 for the base and conditional cases, respectively. Though empirical CDS volatility is lower when macroeconomic conditions improve, the model volatility is also lower. This is due to the fact that equity volatility is an important input into the model volatility and declines as market conditions improve.

For the set of firm-level variables, the volatility of the bid-ask spread is most strongly related to contemporaneous excess volatility. The interquartile range of the standard deviation of the bid-ask spread in our sample is 1.79 basis points,[28] accounting for a difference in excess volatility of an economically important 1.19 percentage points for the base case and 0.58 percentage points for the conditional volatility case. This contrasts the insignificance of the aggregate illiquidity measure, γ, suggesting that CDS-level excess volatility is more

[26] In the Internet Appendix, we also consider the volatility of some of the variables proxying for aggregate conditions.

[27] The coincident indicator is particularly useful in explaining the excess conditional volatility model described in Appendix D whereas the leading indicator explains the excess volatility in our base specification. The fact that the different indicators are significant for the two volatility model specifications reflects the high correlation between the indicators. If we omit the leading indicator, the coincident indicator becomes significant for our base case.

[28] We also consider regressing the standard deviation of the bid-ask spread on firm dummies to take out firm-level means. The residuals from this regression have an interquartile range of 1.31 basis points.

closely tied to a CDS's variation in illiquidity than to aggregate credit market illiquidity conditions. This is consistent with prices being related to illiquidity and therefore, the volatility of returns being related to the volatility of illiquidity.

Overall, our results suggest that the Merton model is capturing some dimension of the empirically observed volatility. Furthermore, the disconnect between empirical and model volatilities is least severe during the Financial Crisis, a period with high fundamental volatility. The disconnect is also most severe for a CDS when the volatility of the bid-ask spread, a measure of the CDS-level variation in illiquidity, is highest, suggesting that there is a strong tie between illiquidity and excess volatility.

6 Conclusion

Using a Merton model with stochastic interest rates and equity volatility as the primary input, we find that the average model corporate bond volatility is 4.66%. This is 2.19 percentage points lower than the average empirical corporate bond volatility, suggesting that there is quantitatively significant excess volatility in the corporate bond market. Similarly, we find excess volatility of 1.92 and 2.84 percentage points in the CDS market if daily or monthly returns are used, respectively.

The two natural candidates to explain this excess volatility are missing fundamentals in the Merton model and illiquidity. In particular, excess volatility could potentially be explained by the Merton model failing to capture fundamentals in relating the equity and credit markets or volatility arising from time-varying illiquidity in credit markets. Fundamentals and illiquidity are the same two explanations that have become the center of the debate on the credit spread puzzle since Huang and Huang (2003) showed that a number of structural models matched to historical default probabilities cannot generate yield spreads as high as those empirically observed. Distinguishing between the two explanations provides evidence as to which direction is particularly important to pursue.

To distinguish between the fundamentals and illiquidity explanations for excess volatility, we consider both the determinants of excess volatility and also the implications of the two explanations for excess volatility. First, we regress excess volatility on proxies for fundamentals and illiquidity, finding that it is the illiquidity proxies that have some relation to excess volatility. Second, we calculate volatilities from bond portfolios and find that excess volatility is markedly reduced when bond-specific factors are diversified away. Overall, our results are consistent with liquidity-based explanations of the failure of structural models of default rather than fundamentals-based explanations.

Tables and Figures

Table 1: **Bond Sample Summary Statistics**

Panel A: Our Corporate Bond Sample									
	2003-2006			2007-2010			Full Period		
	mean	med	std	mean	med	std	mean	med	std
Obs	1,454			1,429			2,883		
Bonds	742			645			1,021		
Maturity	6.50	3.34	7.63	7.27	4.12	9.10	6.88	3.71	8.40
Amt	562	300	736	608	306	829	585	300	784
Rating	6.79	7.00	3.66	7.11	6.00	4.18	6.95	7.00	3.93
Age	6.69	6.52	3.94	8.41	7.86	5.35	7.54	7.04	4.77
Trades	1,282	490	2,376	1,750	741	2,814	1,514	596	2,612
Volume	425	147	767	340	119	620	383	132	699
Turnover	59.07	47.47	46.97	46.77	38.66	36.23	52.97	42.22	42.43
Avg Trd Size	352	272	304	209	144	228	281	196	278
Bond Zero	63.88	71.43	27.88	65.60	75.79	28.66	64.73	73.41	28.28
Amihud	0.92	0.44	1.54	2.08	1.22	2.67	1.49	0.72	2.25
Amihud Vol	1.85	1.45	1.78	3.29	2.43	3.18	2.56	1.79	2.66
IRC	0.24	0.18	0.21	0.40	0.31	0.32	0.32	0.24	0.28
IRC Vol	0.31	0.25	0.26	0.45	0.36	0.36	0.38	0.30	0.32
Panel B: US Corporates in FISD									
Obs	82,402			95,948			178,350		
Bonds	35,586			37,523			53,828		
Maturity	7.62	4.71	8.88	7.82	4.62	8.95	7.73	4.67	8.91
Amt	169	40	338	197	20	498	184	27	432
Rating	7.29	6.00	4.16	7.27	6.00	4.48	7.28	6.00	4.33
Age	4.85	3.38	3.97	5.04	3.96	4.00	4.95	3.74	3.99

Summary statistics for the bonds in our sample (Panel A) and for all US non-Treasury bonds in FISD (Panel B). Observations are reported at the bond-year level. *Bonds* is the number of distinct bonds. *Maturity* is a bond's time to maturity in years. *Amt* is a bond's amount outstanding in $mm of face value. *Rating* is a numerical translation of Moody's rating, where 1=Aaa and 21=C. *Age* is the time since issuance in years. *Trades* is the number of trades in a year for a bond. *Volume* is a bond's trading volume in $mm face value for a year. *Turnover* is Volume/Amount Outstanding for a bond in a year in %. *Avg Trd Size* is the average trade size of a bond in $k of face value. *Bond Zero*, *Amihud*, *Amihud Vol*, *IRC*, and *IRC Vol* are defined and calculated as in Dick-Nielsen, Feldhutter, and Lando (2012). *Bond Zero* is expressed in %. *Amihud*, *Amihud Vol*, *IRC*, and *IRC Vol* are scaled by 100 as compared to Dick-Nielsen, Feldhutter, and Lando (2012).

Table 2: **Firm Summary Statistics**

Panel A: Firms in Our Corporate Bond Sample

	2003-2006			2007-2010			Full Period		
	mean	med	std	mean	med	std	mean	med	std
Firm-Years	376			359			735		
Equity Mktcap	41.48	21.47	56.91	38.63	18.92	55.72	40.09	19.97	56.31
EBIT/Assets	0.10	0.09	0.06	0.09	0.08	0.06	0.10	0.09	0.06
Coverage Ratio	10.21	6.23	12.14	8.73	5.53	9.49	9.49	5.92	10.94
Sales/Assets	0.91	0.76	0.58	0.88	0.75	0.51	0.90	0.76	0.55
RE/Assets	0.21	0.23	0.39	0.21	0.22	0.43	0.21	0.23	0.41
NI/Assets	0.05	0.05	0.06	0.04	0.05	0.07	0.05	0.05	0.06
Assets	45.00	25.13	82.10	49.73	25.12	93.31	47.31	25.12	87.74
Equity B/A	0.18	0.12	0.19	0.09	0.06	0.08	0.13	0.09	0.15
Cash flow vol	0.04	0.02	0.04	0.03	0.02	0.04	0.04	0.02	0.04
Earnings vol	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02
Leverage vol	0.06	0.05	0.05	0.07	0.06	0.04	0.07	0.06	0.05
Sales vol	0.04	0.02	0.04	0.03	0.02	0.03	0.03	0.02	0.03

Panel B: Firms in Our CDS Sample

	2004-2006			2007-2009			Full Period		
	mean	med	std	mean	med	std	mean	med	std
Firm-Years	937			882			1,819		
Equity Mktcap	22.69	10.52	41.84	22.49	9.47	41.43	22.59	10.17	41.63
EBIT/Assets	0.10	0.09	0.06	0.09	0.09	0.07	0.10	0.09	0.07
Coverage Ratio	10.69	6.18	13.72	9.12	5.75	11.03	9.93	5.95	12.51
Sales/Assets	0.97	0.84	0.66	0.97	0.81	0.68	0.97	0.82	0.67
RE/Assets	0.21	0.20	0.31	0.21	0.22	0.32	0.21	0.21	0.32
NI/Assets	0.05	0.05	0.06	0.04	0.05	0.08	0.05	0.05	0.07
Assets	22.10	11.45	48.19	24.18	13.12	34.27	23.11	12.42	42.04
Equity B/A	0.25	0.12	1.32	0.13	0.09	0.27	0.19	0.10	0.97
Cash flow vol	0.04	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Earnings vol	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02
Leverage vol	0.07	0.06	0.05	0.07	0.06	0.04	0.07	0.06	0.04
Sales vol	0.04	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03

Summary statistics for the firms with bonds (Panel A) or CDS (Panel B) in our sample are reported. *Equity Mktcap* is the equity market capitalization of a firm in $bn. *EBIT/Assets* is defined using Compustat data as OIADP/AT. *Coverage Ratio* is defined as (OIADP + XINT)/XINT, following Blume, Lim, and MacKinlay (1998). *Sales/Assets* if defined as SALE/AT. *RE/Assets* is the ratio of retained earnings to assets and is defined as RE/AT. *NI/Assets* is the ratio of Net Income to Assets and is defined as NI/AT. *Assets* is total book assets in $bn. *Equity B/A* is the bid-ask spread of equity in our sample from TAQ at the end of June and December of each year and is expressed as a percentage of stock price. *Cash flow vol* is the volatility of the ratio of cash flows to assets. *Earnings vol* is the volatility of the ratio of earnings to assets. *Leverage vol* is the volatility of firm leverage. *Sales vol* is the volatility fo the ratio of sales to assets. All four vol variables are calculated using the last five years of Compustat quarterly data.

Table 3: **Volatility Estimates**

Panel A: Corporate Bond Sample

	$\hat{\sigma}_D$			$\hat{\sigma}_E$			σ_D^{Merton}		
	mean	med	sd	mean	med	sd	mean	med	sd
2003	7.20	6.71	4.58	26.95	27.59	9.13	5.60	5.17	2.80
2004	4.52	4.06	3.02	18.27	16.47	7.48	3.91	3.72	2.46
2005	4.60	3.48	4.07	20.17	18.95	10.21	3.19	2.87	2.11
2006	4.08	2.91	3.53	18.76	16.63	8.05	2.26	2.07	1.70
2007	4.00	3.12	3.09	18.92	15.49	8.28	3.47	3.66	2.28
2008	13.09	10.38	10.05	38.86	33.59	16.18	6.21	5.63	4.60
2009	15.98	9.95	18.23	54.19	56.01	27.68	10.67	8.75	7.18
2010	5.57	5.01	4.00	32.64	34.04	10.77	4.67	4.69	2.69
Full	6.86	4.55	8.84	27.59	23.04	18.09	4.66	3.75	4.30

Panel B: CDS Sample (Daily Returns Used)

	$\hat{\sigma}_D$			$\hat{\sigma}_E$			σ_D^{Merton}		
	mean	med	sd	mean	med	sd	mean	med	sd
2004	2.58	1.01	13.68	23.02	20.40	11.34	0.99	0.42	2.13
2005	3.01	1.39	7.45	24.53	21.57	13.86	1.04	0.35	2.51
2006	2.49	1.19	5.30	24.70	21.89	12.88	1.05	0.30	2.47
2007	3.29	1.35	6.02	27.45	24.10	15.00	1.52	0.44	3.33
2008	9.78	3.59	32.13	58.52	44.15	45.08	6.87	3.11	7.99
2009	8.63	3.04	24.65	49.80	39.54	39.27	6.32	2.64	7.82
2010	4.00	2.10	5.53	32.34	28.74	16.83	2.82	0.60	4.22
Full	4.87	1.74	17.18	34.55	26.50	29.10	2.95	0.52	5.53

Panel C: CDS Sample (Monthly Returns Used)

	$\hat{\sigma}_D$			$\hat{\sigma}_E$			σ_D^{Merton}		
	mean	med	sd	mean	med	sd	mean	med	sd
2004	2.97	0.97	8.95	22.81	19.86	11.50	0.98	0.44	2.02
2005	3.45	1.41	8.75	23.90	22.12	12.50	1.17	0.36	2.95
2006	2.23	1.07	2.93	22.77	20.71	11.16	0.84	0.24	1.95
2007	3.54	1.61	3.71	23.27	21.10	10.31	1.12	0.40	2.09
2008	9.68	5.06	16.72	48.62	42.26	27.85	7.00	3.71	8.16
2009	12.06	4.78	22.74	49.53	37.81	33.07	5.79	1.73	7.03
Full	5.56	2.09	13.18	31.46	24.98	23.14	2.72	0.48	5.30

The mean, median, and standard deviation of empirical bond and CDS volatilities ($\hat{\sigma}_D$), empirical equity volatilities ($\hat{\sigma}_E$), and model-implied bond and CDS volatilities (σ_D^{Merton}) are reported in %. Panel A reports annualized volatilities for the corporate bond sample where volatilities are calculated each year using monthly returns. Panel B reports annualized volatilities for the CDS sample where volatilities are calculated each month using daily returns. Panel C reports annualized volatilities for the CDS sample where volatilities are calculated each year using monthly returns. Volatilities using monthly CDS returns are not calculated in 2010 as Datastream ceased coverage of CDS prices from CMA Datavision in September 2010.

Table 4: **Volatility Estimates by Bond or Firm Characteristics**

Panel A: Empirical Volatility

Corporate Bonds	2003-2006				2007-2010				All			
	low	Q2	Q3	high	low	Q2	Q3	high	low	Q2	Q3	high
Amt	5.06	4.76	4.47	3.93	10.70	10.17	8.35	7.30	7.97	7.34	6.30	5.68
Maturity	1.45	3.06	5.07	8.79	4.65	7.49	9.41	15.24	3.03	5.28	7.21	11.98
Rating	3.68	4.28	4.15	6.65	5.56	6.00	9.79	17.69	4.57	5.13	7.20	12.11
Equity Vol	3.84	4.15	4.59	5.84	7.17	7.00	6.84	16.67	5.42	5.60	5.77	10.99
Firm K/V	4.00	4.93	4.25	5.19	7.28	9.24	8.02	16.19	5.65	7.08	6.43	8.99
Firm Payout	4.52	3.91	4.64	5.38	7.99	4.75	9.54	14.03	6.44	4.26	7.02	9.81
Bond Zero	4.04	4.18	4.25	5.86	6.86	9.88	10.00	9.84	5.44	6.98	7.08	7.84
Amihud	3.38	4.10	4.74	5.97	7.02	7.02	8.48	14.15	5.17	5.54	6.58	9.99
SD(Amihud)	3.28	3.50	4.49	6.78	5.33	6.71	9.24	15.50	4.29	5.08	6.82	11.07
IRC	2.61	3.55	4.82	7.32	4.13	6.55	10.38	15.45	3.36	5.03	7.57	11.34
SD(IRC)	2.94	3.22	4.76	7.26	3.97	6.54	9.84	16.31	3.45	4.86	7.27	11.72
CDS	2004-2006				2007-2009				All			
	low	Q2	Q3	high	low	Q2	Q3	high	low	Q2	Q3	high
Firm Rating	0.73	1.36	2.59	8.45	2.33	4.27	7.29	24.44	1.48	2.76	5.07	16.05
CDS Spread	0.52	0.90	2.23	7.91	1.73	2.94	6.06	23.00	1.11	1.89	4.09	15.25
Equity Vol	0.98	1.52	2.47	6.57	2.60	3.66	6.25	21.22	1.76	2.55	4.30	13.70
Firm K/V	1.20	1.54	2.41	6.39	2.70	4.44	7.44	19.13	1.93	2.94	4.85	12.59
CDS B/A Spread	0.72	1.20	2.11	7.55	2.06	3.66	5.98	22.12	1.38	2.36	3.99	14.64

Panel B: Model Volatility

Corporate Bonds	2003-2006				2007-2010				All			
	low	Q2	Q3	high	low	Q2	Q3	high	low	Q2	Q3	high
Amt	3.20	3.27	3.28	3.12	6.23	6.35	6.14	5.78	4.77	4.74	4.63	4.50
Maturity	0.92	2.42	4.04	5.55	3.57	5.43	7.19	8.37	2.23	3.93	5.60	6.95
Rating	3.12	3.30	2.99	3.60	5.27	4.56	5.95	9.63	4.14	3.92	4.59	6.58
Equity Vol	3.18	3.13	3.18	3.41	4.67	4.08	6.26	9.92	3.89	3.61	4.79	6.51
Firm K/V	3.08	3.37	3.01	3.45	4.87	5.91	6.65	7.72	3.98	4.64	5.11	4.93
Firm Payout	3.25	3.11	3.24	3.31	5.93	4.09	6.44	7.74	4.73	3.52	4.80	5.58
Bond Zero	3.05	3.07	3.16	3.62	5.89	6.52	6.01	6.15	4.46	4.77	4.56	4.88
Amihud	2.51	3.07	3.58	3.76	4.54	5.59	6.53	8.08	3.50	4.31	5.03	5.88
SD(Amihud)	2.28	2.66	3.41	4.58	3.95	5.43	6.89	8.76	3.10	4.02	5.12	6.63
IRC	2.05	2.92	3.65	4.29	3.29	5.83	7.07	8.46	2.66	4.36	5.34	6.35
SD(IRC)	2.24	2.59	3.59	4.49	3.29	5.35	7.10	9.04	2.76	3.95	5.33	6.73
CDS	2004-2006				2007-2009				All			
	low	Q2	Q3	high	low	Q2	Q3	high	low	Q2	Q3	high
Firm Rating	0.35	0.43	0.63	3.04	1.21	2.82	4.54	12.05	0.75	1.58	2.69	7.32
CDS Spread	0.33	0.36	0.47	2.85	0.94	1.72	4.11	11.48	0.63	1.02	2.23	7.05
Equity Vol	0.33	0.35	0.42	2.91	0.54	1.11	4.32	12.28	0.43	0.72	2.31	7.47
Firm K/V	0.35	0.43	0.73	2.49	0.96	2.09	4.51	10.69	0.64	1.23	2.56	6.48
CDS B/A Spread	0.35	0.39	0.58	2.69	1.17	2.42	3.98	10.75	0.75	1.35	2.23	6.61

All volatilities are annualized and expressed as percentages. Panel A reports empirical volatilities for corporate bonds and CDS. Panel B reports model volatilities for corporate bonds and CDS. Volatilities are calculated each year using monthly returns. The variable given in each row is the variable that is sorted on. Sorts are done each year and the average, contemporaneous volatilities are reported. Note that in the case of a tie in the sorting variable, a bond is put in the lower category. Thus, quartiles typically do not have exactly 25% of the observations. *Amt*, *Maturity*, *Rating*, *Bond Zero*, *Amihud*, *SD(Amihud)*, *IRC*, and *SD(IRC)* are as defined in Table 1. *Equity Vol* is the annualized equity volatility of the underlying firm calculated using monthly returns. *Firm K/V* is the ratio of the face value of debt to the total value of a firm. *Firm Payout* is the payout ratio of a firm. *Firm Rating* is the S&P long-term credit rating of a firm from Compustat where a lower number is a better rating. *CDS Spread* is the mid price for CDS from Datastream (bpm). *CDS B/A Spread* is the difference between the offer price (bpo) and bid price (bpb) for CDS.

Table 5: **Data Estimated vs. Model Implied Bond Volatility**

	$\hat{\sigma}_D - \sigma_D^{Merton}$						$\hat{\sigma}_D$	σ_D^{Merton}
	#obs	mean	t-stat	25th	median	75th	mean	mean
Straight	2,883	2.19	2.74	-0.18	0.58	2.68	6.86	4.66
Callable	9,322	2.71	2.29	-0.39	0.84	3.44	8.42	5.71
By Year								
2003	94	1.60	1.59	-0.89	0.35	2.63	7.20	5.60
2004	362	0.61	4.69	-0.14	0.17	0.77	4.52	3.91
2005	525	1.41	6.41	-0.20	0.49	2.00	4.60	3.19
2006	473	1.82	10.23	0.23	0.84	2.62	4.08	2.26
2007	358	0.52	2.92	-0.54	0.07	0.95	4.00	3.47
2008	279	6.87	10.04	2.00	4.65	10.71	13.09	6.21
2009	347	5.32	1.90	-1.99	1.71	8.04	15.98	10.67
2010	445	0.90	2.79	-0.69	0.28	1.86	5.57	4.67
By Rating								
Aaa & Aa	723	0.45	0.81	-0.61	0.07	1.05	4.96	4.51
A	1,038	1.20	2.55	-0.19	0.32	1.80	4.98	3.78
Baa	621	2.71	2.66	0.01	0.97	3.51	7.23	4.51
Junk	451	6.41	2.24	1.17	2.89	7.05	13.66	7.25
By Time to Maturity								
0 - 2	882	0.80	3.40	-0.08	0.31	1.32	2.88	2.08
2 - 4	627	1.30	2.16	-0.57	0.07	1.65	5.67	4.37
4 - 6	311	1.27	1.39	-0.64	0.18	1.47	6.45	5.17
6 - 8	264	1.60	2.70	-0.37	0.55	2.46	7.36	5.76
8+	799	5.00	3.08	0.81	2.73	6.29	12.18	7.18

Statistics relating to the difference between empirically estimated bond volatility and model-implied bond volatility are reported in all but the last two columns. The last two columns report the mean empirical and model volatilities, respectively. Volatilities are expressed in % and are calculated each year using monthly returns. The main sample uses data from 2003 to 2010 and excludes putable, convertible, and callable bonds. *t-stats* are calculated using standard errors clustered by time and by firm, with the exception of the by-year results which use standard errors clustered by firm.

Table 6: **Data Estimated vs. Model Implied CDS Volatility**

	$\hat{\sigma}_D - \sigma_D^{Merton}$						$\hat{\sigma}_D$	σ_D^{Merton}
Panel A: Daily Returns								
	#obs	mean	t-stat	25th	median	75th	mean	mean
2004	2,546	1.59	5.47	0.17	0.53	1.22	2.58	0.99
2005	3,954	1.97	6.69	0.37	0.87	2.11	3.01	1.04
2006	4,190	1.44	8.95	0.28	0.69	1.65	2.49	1.05
2007	4,129	1.77	6.83	0.18	0.67	1.97	3.29	1.52
2008	3,852	2.91	2.90	-3.25	0.48	2.23	9.78	6.87
2009	3,489	2.31	3.12	-2.26	0.57	1.69	8.63	6.32
2010	2,740	1.18	4.04	0.26	0.88	2.05	4.00	2.82
Full	24,900	1.92	7.23	0.12	0.68	1.86	4.87	2.95
Panel B: Monthly Returns								
	#obs	mean	t-stat	25th	median	75th	mean	med
2004	287	1.99	4.38	0.00	0.42	1.71	2.97	0.98
2005	319	2.28	5.81	0.31	0.99	2.72	3.45	1.17
2006	331	1.39	10.87	0.25	0.70	1.58	2.23	0.84
2007	302	2.42	14.15	0.51	1.09	3.70	3.54	1.12
2008	268	2.69	3.41	-0.96	1.61	2.98	9.68	7.00
2009	312	6.27	5.78	0.77	1.87	5.12	12.06	5.79
Full	1,819	2.84	3.77	0.26	1.02	2.82	5.56	2.72
Panel C: Conditional Volatility Case								
	#obs	mean	t-stat	25th	median	75th	mean	med
2004	2,485	2.09	2.48	-0.12	0.50	0.96	3.90	1.80
2005	3,638	2.15	3.99	0.40	0.92	1.78	3.78	1.62
2006	3,637	1.06	7.05	0.35	0.67	1.23	2.37	1.31
2007	3,496	1.56	6.05	0.49	0.90	1.78	3.08	1.52
2008	3,317	1.73	2.76	-1.79	1.26	2.85	9.29	7.56
2009	3,176	0.01	0.02	-2.53	0.12	1.68	8.60	8.59
2010	2,331	0.73	1.72	-0.42	0.85	1.61	4.08	3.36
Full	22,080	1.35	5.34	-0.52	0.74	1.70	5.00	3.65

Statistics relating to the difference between empirically estimated CDS volatility and model-implied CDS volatility are reported in all but the last two columns. The last two columns report the mean empirical and model volatilities, respectively. Volatilities are expressed in annualized % and are calculated each month using daily returns in Panel A and each year using monthly returns in Panel B. In Panel C, volatilities are calculated each month using daily data, but model volatilities are calculated as described in Appendix D. The full sample uses data from 2004 to 2010 in Panels A and C and 2004 to 2009 in Panel B. *t-stats* are calculated using standard errors clustered by time and by firm, with the exception of the by-year results in Panel B which use White standard errors.

Table 7: **Data Estimated vs. Model Implied Volatility, Overlapping Sample**

	Obs	Mean	t-stat	25th	50th	75th
Corporate Bonds	1,954	2.72	2.41	-0.02	0.72	2.94
CDS	542	2.56	2.98	0.20	0.82	2.37

The difference between empirically estimated bond and CDS volatility and model-implied and CDS bond volatility. Volatilities are in %. Only firm-years that are in both the corporate bond and CDS sample are included. *t-stats* are calculated using standard errors clustered by time and by firm.

Table 8: **Excess Bond Volatility and Firm- and Bond-Level Characteristics**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Rating	0.227	0.331	0.246	0.348	0.268	0.271	0.245
	(4.45)	(6.21)	(5.58)	(5.56)	(4.55)	(4.46)	(3.94)
Maturity	0.119	0.121	0.0907	0.169	0.126	0.131	0.104
	(5.66)	(5.72)	(3.69)	(7.19)	(5.51)	(5.61)	(4.73)
Age	0.0239		0.0202		-0.00678		-0.00660
	(0.79)		(0.70)		(-0.25)		(-0.23)
log(Amt)	-0.108		0.166		-0.113		0.272
	(-1.30)		(0.99)		(-0.69)		(1.42)
B/A Spread	3.834		1.920		2.646		1.427
	(3.35)		(1.95)		(3.21)		(1.60)
SD(B/A Spread)	8.744		6.885		3.954		3.265
	(1.93)		(1.95)		(1.47)		(1.30)
Bond Zero	0.000314		0.00232		0.0143		0.0161
	(0.04)		(0.38)		(2.21)		(2.22)
Amihud		-0.128	-0.0119			-0.196	-0.141
		(-1.18)	(-0.11)			(-1.63)	(-1.35)
Implied Round Trip		2.720	1.390			3.648	2.223
		(2.24)	(1.18)			(2.92)	(1.71)
SD(Amihud)		0.210	0.196			0.167	0.188
		(2.63)	(2.93)			(2.06)	(2.31)
SD(Implied Round Trip)		0.951	1.161			-0.439	0.0459
		(0.88)	(1.36)			(-0.68)	(0.07)
EBIT/Assets				-1.553	-2.936	-0.0566	-1.258
				(-0.31)	(-0.59)	(-0.01)	(-0.26)
Coverage Ratio				0.0192	0.0193	0.0119	0.0117
				(1.30)	(1.51)	(0.90)	(0.90)
Sales/Assets				-0.0842	-0.0182	-0.0336	-0.0692
				(-0.24)	(-0.06)	(-0.13)	(-0.26)
RE/Assets				-0.398	-0.531	-0.660	-0.638
				(-1.23)	(-1.43)	(-1.87)	(-1.48)

NI/Assets				0.746	2.636	1.353	2.985
				(0.10)	(0.38)	(0.19)	(0.43)
log(Assets)				-0.00489	0.109	-0.162	-0.0496
				(-0.03)	(0.88)	(-1.20)	(-0.35)
Cash flow vol				5.457	6.029	3.330	5.330
				(1.26)	(1.42)	(0.86)	(1.32)
Earnings vol				-3.201	-5.734	-1.297	-4.059
				(-0.41)	(-0.81)	(-0.18)	(-0.59)
Leverage vol				-2.961	-2.737	-2.822	-2.147
				(-0.53)	(-0.59)	(-0.55)	(-0.47)
Sales vol				7.737	2.821	1.454	0.0284
				(2.06)	(0.75)	(0.31)	(0.01)
Observations	2,552	2,609	2,432	2,333	2,088	2,146	1,988
R-squared	0.407	0.399	0.435	0.335	0.365	0.357	0.373
Within-group R^2	0.302	0.307	0.343	0.223	0.254	0.260	0.273

All regressions include time fixed-effects. The dependent variable is $\hat{\sigma}_D - \sigma_D^{Merton}$, where $\hat{\sigma}_D$ is the realized volatility of a corporate bond using monthly returns in a calendar year and σ_D^{Merton} is the volatility implied by the Merton model and realized equity volatility. Both are expressed in annualized %. *Rating* is a bond's Moody rating where Aaa = 1 and C = 21. *Maturity* is a bond's time to maturity in years. *Age* is a bond's time since issuance in years. *Amt* is a bond's amount outstanding in $mm face value. *B/A Spread* is a bond's bid-ask spread divided by its mid price, scaled by 100. *SD(B/A Spread)* is the standard deviation of a bond's bid-ask spread divided by its mid price, scaled by 100. *Bond Zero* is the percentage of days that a bond does not have at least one trade of $100k, following Dick-Nielsen, Feldhutter, and Lando (2012). *Amihud* is the Amihud measure and *IRC* is an implied round-trip cost measure. *SD(Amihud)* and *SD(IRC)* are the standard deviations of these measures. *Amihud*, *IRC*, *SD(Amihud)*, and *SD(IRC)* are defined as in Dick-Nielsen, Feldhutter, and Lando (2012), but scaled by 100 here. *EBIT/Assets* is defined using Compustat data as OIADP/AT. *Coverage Ratio* is defined as (OIADP + XINT)/XINT. *Sales/Assets* is defined as SALE/AT. *Retained Earnings/Assets* is defined as RE/AT. *Net Income/Assets* is defined as NI/AT. *Assets* is total book assets in $mm. *Cash flow vol* is the volatility of cashflows divided by total assets. *Earnings vol* is the volatility of earnings divided by assets. *Leverage vol* is the volatility of leverage. *Sales vol* is the volatility of sales divided by assets. *Cash flow vol*, *Earnings vol*, *Leverage vol*, and *Sales vol* are calculated using the last 5 years of quarterly data. *t-stats* are in parentheses and use standard errors clustered by firm.

Table 9: **Excess CDS Volatility and Firm- and Bond-Level Characteristics**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Base	Base	Base	Short-run	Short-run	Short-run	Base	Base	Base
CDS Spread	0.0117	0.000656	0.00155	0.00513	-0.00214	-0.000711	0.0227	0.0189	0.0207
	(12.91)	(0.78)	(1.73)	(4.69)	(-1.66)	(-0.54)	(14.01)	(5.64)	(6.03)
EBIT/Assets	6.045		4.831	0.853		0.890	5.360		3.404
	(3.26)		(3.17)	(0.36)		(0.40)	(1.40)		(0.98)
Coverage Ratio	-0.00332		-0.00395	-0.00592		-0.00549	-0.00184		-0.00270
	(-0.72)		(-1.03)	(-1.04)		(-1.01)	(-0.24)		(-0.38)
Sales/Assets	-0.147		-0.0687	-0.0193		0.0484	0.217		0.113
	(-1.18)		(-0.73)	(-0.15)		(0.47)	(1.17)		(0.69)
Retained Earnings/Assets	0.525		0.290	0.635		0.479	1.437		0.921
	(1.43)		(0.93)	(1.45)		(1.15)	(2.38)		(1.63)
Net Income/Assets	0.853		-0.425	7.347		5.308	0.236		3.583
	(0.45)		(-0.27)	(2.90)		(2.27)	(0.05)		(0.87)
log(Assets)	0.337		0.265	0.360		0.309	0.563		0.335
	(4.47)		(3.81)	(3.22)		(2.69)	(4.10)		(2.15)
CDS B/A		0.00850	0.0118		-0.0167	-0.0178		-0.187	-0.184
		(0.36)	(0.49)		(-0.56)	(-0.60)		(-2.73)	(-2.50)
SD(CDS B/A)		0.713	0.693		0.489	0.468		0.394	0.380
		(11.42)	(10.68)		(6.20)	(5.83)		(7.04)	(6.59)
Observations	24,294	24,900	24,294	21,667	22,080	21,667	1,794	1,819	1,794
R-squared	0.253	0.381	0.388	0.120	0.195	0.205	0.594	0.634	0.644
Within-group R^2	0.226	0.358	0.365	0.068	0.148	0.158	0.580	0.621	0.632

All regressions include time fixed-effects. The dependent variable is $\hat{\sigma}_D - \sigma_D^{Merton}$, where $\hat{\sigma}_D$ is the realized CDS volatility and σ_D^{Merton} is the volatility implied by the Merton model and equity volatility. Both are expressed in annualized %. Columns (1)-(3) use CDS volatilities calculated each month from daily returns as described in Section 2. Columns (4)-(6) use CDS volatilities calculated each month from daily returns as described in Appendix D. Columns (7) to (9) use CDS volatilities calculated each year using monthly returns. *CDS Spread* is the CDS spread in basis points. *EBIT/Assets* is defined using Compustat data as OIADP/AT. *Coverage Ratio* is defined as (OIADP + XINT)/XINT. *Sales/Assets* is defined as SALE/AT. *Retained Earnings/Assets* is defined as RE/AT. *Net Income/Assets* is defined as NI/AT. Assets is the book value of assets in \$mm. *CDS B/A* is the bid-ask spread of CDS in basis points. *SD(CDS B/A)* is the standard deviation of the CDS bid-ask spread in basis points. *t-stats* are in parentheses and use standard errors clustered by firm.

Table 10: **Time-Series Relation between Empirical and Model Volatilities**

	(1)	(2)	(3)	(4)
	$\hat{\sigma}_D$	$\hat{\sigma}_{CDS}$	$\hat{\sigma}_{CDS}$	$\hat{\sigma}_{CDS}$
σ_D^{Merton}	1.14			
	(2.60)			
σ_{CDS}^{Merton}		1.38	0.78	0.84
		(1.52)	(-8.54)	(-5.77)
Observations	2,883	1,819	24,900	22,080
Within-group R^2	0.443	0.463	0.337	0.447
Return Horizon	Monthly	Monthly	Daily	Daily
Calibration	Base	Base	Base	Short-run

Regressions of empirical volatilities on model volatilities with bond-level fixed effects. The first two columns use volatilities calculated each year from monthly returns of corporate bonds and CDS, respectively. The last two columns use volatilities calculated each month from daily returns on CDS. Column 3 uses the base methodology described in 4.3. Column 4 uses the methodology described in Appendix D. Standard errors are clustered by time and t-stats are reported. Reported R^2 values are within-group R^2's.

Table 11: **Excess CDS Volatility and Macroeconomic Factors and Liquidity**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Base	Base	Base	Base	Cond	Cond	Cond	Cond
Δ VIX	-0.0003	-0.0010		0.0044	-0.0017	-0.0183		0.0092
	(-0.01)	(-0.02)		(0.07)	(-0.03)	(-0.25)		(0.15)
Δ Consumer Sentiment	-0.0099	-0.0406		-0.0228	-0.0046	-0.0336		-0.0103
	(-0.44)	(-1.71)		(-0.84)	(-0.19)	(-1.37)		(-0.40)
Δ Business Cond Index	-0.0001	-0.0075		0.0066	0.0068	0.0002		0.0101
	(-0.01)	(-0.76)		(0.61)	(0.72)	(0.02)		(1.03)
Δ Repo Rate	0.0937	0.232		-0.0748	-0.765	-0.765		-0.817
	(0.12)	(0.34)		(-0.08)	(-1.07)	(-1.25)		(-1.02)
Δ LIBOR	-0.520	-0.675		-0.227	-0.0149	-0.298		0.182
	(-0.93)	(-1.38)		(-0.30)	(-0.03)	(-0.57)		(0.28)
Δ Term Spread	-0.0839	0.390		-0.105	-0.287	-0.0866		-0.178
	(-0.10)	(0.42)		(-0.10)	(-0.30)	(-0.09)		(-0.18)
Δ Credit Spread	-0.241	-0.347		-0.747	-0.567	-0.806		-0.790
	(-0.72)	(-1.06)		(-1.54)	(-1.40)	(-2.10)		(-1.64)
Δ CDS Index	0.0312	0.186		-0.181	-0.127	0.0167		-0.233
	(0.12)	(0.71)		(-0.42)	(-0.39)	(0.06)		(-0.62)
Δ ci	0.297	0.271		0.910	0.810	0.674		1.119
	(1.18)	(0.99)		(2.51)	(2.61)	(2.05)		(3.15)
Δ lead	0.403	0.438		0.411	-0.0865	0.0919		-0.0960
	(2.23)	(2.34)		(2.05)	(-0.44)	(0.48)		(-0.50)
$\Delta\gamma$		0.179				0.791		
		(0.25)				(0.84)		
Stock Market Return	-0.0079	0.0487		0.0282	-0.0432	0.0075		-0.0341
	(-0.16)	(0.89)		(0.44)	(-0.73)	(0.12)		(-0.49)
Bond Market Return	0.0186	0.0619		-0.0618	-0.0644	-0.0023		-0.0860
	(0.18)	(0.52)		(-0.47)	(-0.57)	(-0.02)		(-0.68)
Stock Return			0.0372	0.0145			0.0244	0.0248
			(2.08)	(1.39)			(1.62)	(2.04)
Δ CDS Spread			0.0044	0.0073			0.0026	0.0038
			(1.39)	(2.17)			(0.82)	(1.35)
SD(CDS B/A)			0.664	0.713			0.323	0.347
			(22.16)	(16.81)			(7.84)	(10.33)
Δ CDS B/A			-0.0196	-0.0193			-0.0037	-0.0059
			(-1.12)	(-1.14)			(-0.22)	(-0.38)
Observations	24,731	20,231	24,681	24,672	21,906	17,996	21,895	21,884
R-squared	0.210	0.227	0.380	0.411	0.174	0.177	0.241	0.261
Within-group R^2	0.012	0.019	0.227	0.266	0.011	0.017	0.091	0.114

Reported are panel regressions with CDS fixed-effects. The dependent variable is the difference between empirical CDS volatility and model volatility, expressed in annualized %. Volatilities are calculated each month using daily returns. The first four columns use the base calibration described in Section 4. The last four columns use the calibration described in Section D. *VIX* is the CBOE VIX index, expressed in %. *Consumer Sentiment* is the University of Michigan Consumer Sentiment Index. *Business Cond Index* is the National Association of Purchasing Management's Business Conditions Index (from Capital IQ). *Repo Rate* is the 3-month repo rate in %. *LIBOR* is the 3-month LIBOR rate in %. *Term Spread* is the difference between the yield of a 10-year Treasury and a 2-year Treasury expressed in %, where yields are from the Constant Maturity Treasury series. *Credit Spread* is the difference between Barclays Baa and Aaa intermediate index yields in %. *CDS Index* is the average of CDS spreads in our sample in %. *ci* and *lead* are the Conference Board's coincident and leading indicators, respectively. γ is the aggregate bond illiquidity measure from Bao, Pan, and Wang (2011). *Stock Market Return* is the return of the S&P 500 Index in %. *Bond Market Return* is the return to the Barclay's US Corporate Investment Grade Index in %. *Stock Return* is the return to the stock of the underlying issuer in %. *CDS Spread* is the mid price of CDS expressed in basis points. *CDS B/A* is the bid-ask spread of the CDS in basis points. *SD(CDS B/A)* is the volatility of the CDS bid-ask spread in a month. All variables are contemporaneous. *t-stats* use standard errors clustered by time.

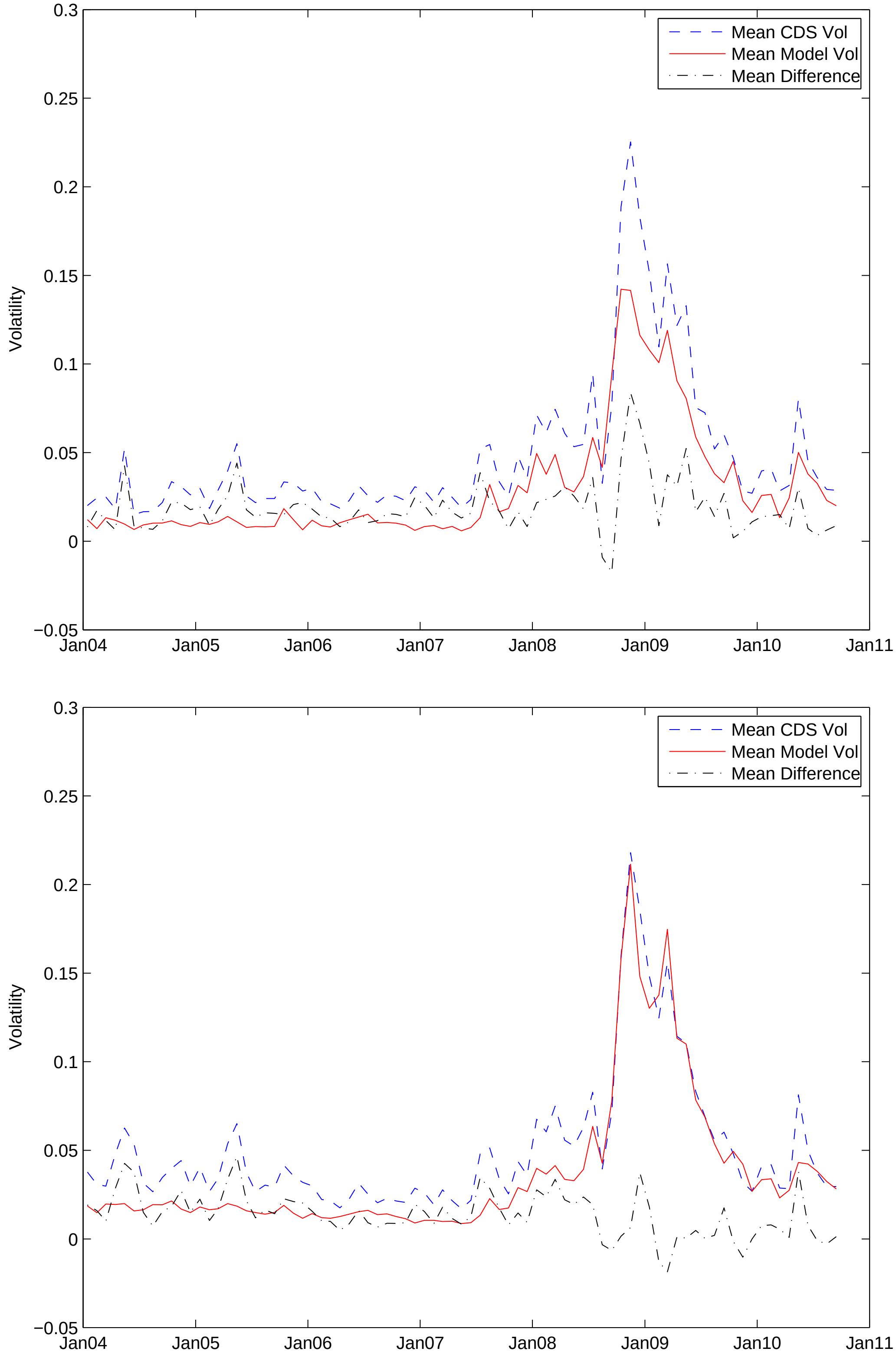

Figure 1: Mean empirical, model, and excess volatility for CDS. Volatilities are calculated each month using daily returns and annualized. The top panel corresponds to our base estimation. The bottom panel corresponds to our conditional volatility estimates.

Appendix

A Interest Rate Calibration

The calibrations for model asset and bond volatility described in Section 2 require Vasicek interest rate parameters, κ, θ, and σ_r. Here, we describe the data and methodology used to determine the Vasicek parameters. We use the 3-month and 7-year Constant Maturity Treasury (CMT) series provided by the U.S. Department of Treasury and the Federal Reserve. This yield curve uses close-of-business bid yields for on-the-run securities as inputs and is considered a par curve. Among the inputs are the most recently auctioned 13-week and 7-year Treasury securities.[29]

Using the daily time-series of 3-month Treasury bill rates from 1982 through 2010, we first estimate θ, the long run short-rate, as the mean of the 3-month Treasury time-series, 4.84%. The mean reversion parameter, κ, is estimated to be 0.1526, so that the daily autocorrelation in the Vasicek model matches the sample autocorrelation.

We estimate σ_r, the volatility of the short rate period-by-period by matching the empirically observed volatility of 7-year Treasury bond returns. First, we estimate the return to 7-year Treasury bonds by using the 7-year CMT series. Noting that the CMT curve is a par curve, a 7-year bond at time t with a yield coupon rate equal to the 7-year yield (y_t) trades at par. At $t+1$, the value of this bond can be re-calculated using y_{t+1} to discount the coupon rate of y_t and the par value of the bond. We can then calculate the return to a 7-year Treasury bond. Using daily returns, we calculate volatilities each month and using monthly returns, we calculate volatilities each year.

[29] An alternative to the CMT series is the CRSP Treasury Fixed Term Indices. However, bonds in this series are not necessarily on-the-run and may be less liquid. The returns to 7-year bonds calculated using our methodology below and the returns to the 7-year bond in the CRSP data have a correlation of 0.98.

Table A.1: **Treasury Volatility**

	Daily Returns Used			Monthly Returns Used		
	mean	med	std	mean	med	std
2003	7.06	7.32	1.39	8.74	N/A	N/A
2004	5.74	5.61	1.12	6.40	N/A	N/A
2005	4.38	4.45	0.61	4.79	N/A	N/A
2006	3.74	3.82	0.63	3.29	N/A	N/A
2007	5.32	5.33	2.01	5.31	N/A	N/A
2008	9.59	9.48	2.42	7.92	N/A	N/A
2009	8.67	8.17	2.94	7.36	N/A	N/A
2010	6.55	6.16	1.68	6.37	N/A	N/A
Full	6.38	5.67	2.56	6.27	6.39	1.78

Annualized volatility of 7-year Treasury bond returns expressed in %. In the first set of columns, daily Treasury returns are used to calculate volatility each month. In the second set of columns, monthly Treasury returns are used to calculate volatilities each year.

Under the Vasicek model, the price of a 7-year Treasury bond is

$$P_{Treas} = \sum_{t=1}^{14} exp\left(a\left(\frac{t}{2}\right) + b\left(\frac{t}{2}\right) r_0\right)\frac{c}{2} + exp\left(a\left(7\right) + b\left(7\right) r_0\right) \tag{7}$$

and the relation between Treasury volatility and σ_r is given by

$$\sigma^2_{Treas} = \left(\frac{\partial \ln P_{Treas}}{\partial r}\right)^2 \sigma^2_r \tag{8}$$

Using the empirical volatility of the 7-year Treasury returns along with the previously estimated κ and θ, we can estimate σ_r each period. Though our estimates of σ_r vary each period with empirical Treasury volatility, the mean estimate is 1.59% when monthly Treasury returns are used and 1.58% when daily Treasury returns are used.

B Model Details

B.1 Asset Volatility

To estimate asset volatility, we use the Shimko, Tejima, and van Deventer (1993) extension of the Merton (1974) model where equity value is

$$E_t = V_t\, e^{-\delta\tau}\, N(d_1) - K\, e^{a(\tau)+b(\tau)\, r_t}\, N(d_2), \tag{9}$$

where $\tau = T - t$ is the time-to-maturity of the firm's debt, $N(\cdot)$ is the cumulative distribution function for a standard normal, $d_1 = d_2 + \sqrt{\Sigma}$,

$$d_2 = \frac{\ln(V/K) - a(\tau) - b(\tau) r_t - \delta\tau - \frac{1}{2}\Sigma}{\sqrt{\Sigma}}, \tag{10}$$

$$\Sigma = \tau(\sigma_v^2 + \frac{\sigma_r^2}{\kappa^2}) + \frac{2\sigma_r^2}{\kappa^3}(e^{-\kappa\tau} - 1) - \frac{\sigma_r^2}{2\kappa^3}(e^{-2\kappa\tau} - 1), \tag{11}$$

and where $a(\tau)$ and $b(\tau)$ are the exponents of the discount function of the Vasicek model:

$$b(\tau) = \frac{e^{-\kappa\tau} - 1}{\kappa}\, ; \quad a(\tau) = \theta\left(\frac{1 - e^{-\kappa\tau}}{\kappa} - \tau\right) + \frac{\sigma^2}{2\kappa^2}\left(\frac{1 - e^{-2\kappa\tau}}{2\kappa} - 2\frac{1 - e^{-\kappa\tau}}{\kappa} + \tau\right). \tag{12}$$

The sensitivities of equity returns to the random shocks in asset returns and risk-free rates is:

$$\frac{\partial \ln E_t}{\partial \ln V_t} = \frac{1}{1 - \mathcal{L}} \quad \text{and} \quad \frac{\partial \ln E_t}{\partial r_t} = \frac{-b(\tau)\, \mathcal{L}}{1 - \mathcal{L}}\, ,$$

where

$$\mathcal{L} = \frac{K}{V}\, \frac{N(d_2)}{N(d_1)}\, \exp\left(\delta\, \tau + a(\tau) + b(\tau)\, r_t\right)\, . \tag{13}$$

Combining the above equations, with equation (5), we have

$$\sigma_E^2 = \left(\frac{1}{1 - \mathcal{L}}\right)^2 \sigma_v^2 + \left(\frac{\mathcal{L}}{1 - \mathcal{L}}\right)^2 b(\tau)^2\, \sigma_r^2\, . \tag{14}$$

B.2 Firm-Level Variables

A key parameter that enters equation (14) is the ratio K/V, where K is the book value of debt and V is the market value of the firm. We calculate the book debt K using the sum of long-term debt and debt in current liabilities from Compustat, and approximate the firm value V by its definition $V = S + D$, where S is the market value of equity and D is the market value of debt. To estimate the market value of debt D, we start with the book value of debt K. To further improve on this approximation, we collect, for each firm, all of its bonds in TRACE, calculate an issuance weighted market-to-book ratio, and multiply K by this ratio.

In addition, two other parameters that enter equation (14) are the firm-level debt maturity T and the firm's payout ratio δ. Taking into account the actual maturity structure of the firm, we collect, for each firm, all of its bonds in FISD and calculate the respective durations. We let the firm-level T be the issuance-weighted duration of all the bonds in our sample. Effectively, we acknowledge the fact that firm's maturity structure is more complex than the zero-coupon structure assumed in the Merton model, and our issuance-weighted duration is an attempt to map the collection of coupon bonds to the maturity of a zero-coupon bond. To calculate the payout ratio δ, we first take a firm's average coupon payment times its face value K and add this to its equity dividends from Compustat. We then scale this sum by firm value V, with the details of calculating V summarized above. Estimating the asset volatility, σ_v, then relies on using the variables described in this section (K, V, δ, T), interest rate parameters described in Appendix A $(\kappa, \theta, \sigma_r, r)$, equity volatility, and equation (14) to calculate an implied asset volatility.

B.3 Bond Pricing

To calculate corporate bond prices in our setting, it is important to calculate:

$$E^Q \left[\exp \left(- \int_0^{T_2} r_s ds \right) \mathbf{1}_{\{V_{T_1} > K\}} \right] \tag{15}$$

where $T_2 \geq T_1$

$$E^Q \left[\exp \left(- \int_0^{T_2} r_s ds \right) 1_{\{V_{T_1} > K\}} \right] = \exp \left(a(T_2) + b(T_2) r_0 \right) N \left(d_3 \right) \tag{16}$$

where

$$d_3 = \frac{\ln\left(\frac{V}{K}\right) - a(T_1) - b(T_1)r_0 - \delta T_1 - \frac{1}{2}\Sigma + \sigma_r^2 \frac{b(T_2-T_1)}{\kappa}\left(-b(T_1) + \frac{\exp(-2\kappa T_1)-1}{2\kappa}\right)}{\sqrt{\Sigma}}$$

$$\Sigma = T_1\left(\sigma_v^2 + \frac{\sigma_r^2}{\kappa^2}\right) + \frac{2\sigma_r^2}{\kappa^3}\left(e^{-\kappa T_1} - 1\right) - \frac{\sigma_r^2}{2\kappa^3}\left(e^{-2\kappa T_1} - 1\right)$$

Proof. It can be shown that the above equation satisfies the PDE for arbitrage-free prices:

$$g \cdot r = g_t + g_v(r-\delta)V + \frac{1}{2}g_{vv}V^2\sigma_v^2 + g_r\kappa(\theta - r) + \frac{1}{2}g_{rr}\sigma_r^2 \tag{17}$$

$$\begin{aligned}
g &= \exp(a(T_2) + b(T_2)r_0)N(d_3) \\
g_v &= \frac{Dn(d_3)}{V\sqrt{\Sigma}}, \text{where } D = \exp\left(a(T_2) + b(T_2)r_0\right) \\
g_{vv} &= -\frac{Dd_3 n(d_3)}{V^2\Sigma} - \frac{Dn(d_3)}{V^2\sqrt{\Sigma}} \\
g_r &= Db(T_2)N(d_3) - \frac{Dn(d_3)b(T_1)}{\sqrt{\Sigma}} \\
g_{rr} &= D(b(T_2))^2N(d_3) - 2Db(T_2)n(d_3)\frac{b(T_1)}{\sqrt{\Sigma}} - Dn(d_3)d_3\frac{(b(T_1))^2}{\Sigma} \\
g_t &= -DN(d_3)(\theta\kappa b(T_2) + \frac{\sigma_r^2}{2}(b(T_2))^2 - e^{-\kappa T_2}r) \\
&\quad - \frac{Dn(d_3)}{\sqrt{\Sigma}}(-\delta - \theta\kappa b(T_1) - \sigma_r^2(b(T_1))^2 + e^{-\kappa T_1}r - \frac{1}{2}\sigma_v^2 \\
&\quad + \sigma_r^2\frac{b(T_2-T_1)}{\kappa}(e^{-\kappa T_1} - e^{-2\kappa T_1})) + Dn(d_3)\frac{d_3}{2\Sigma}(\sigma_v^2 + \sigma_r^2(b(T_1))^2)
\end{aligned}$$

After some algebra, we can verify that g satisfies the PDE.

Boundary condition:

$T_1 \to 0$

$$E^Q\left[\exp\left(-\int_0^{T_2} r_s ds\right)\mathbf{1}_{\{V_{T_1}>K\}}\right] \to \begin{cases} 0 & \text{if V < K} \\ \exp\left(a(T_2-T_1) + b(T_2-T_1)r_{T_1}\right) & \text{if V > K} \end{cases} \quad \blacksquare$$

Special cases include:

1. $T_1 = T_2$

   $$E^Q\left[\exp\left(-\int_0^T r_s ds\right)\mathbf{1}_{\{V_T>K\}}\right] = \exp\left(a(T) + b(T)r_0\right)N(d_2)$$

   where d_2 is as defined in equation (10).

2. $K = 0$ (no default)

$$E^Q\left[\exp\left(-\int_0^T r_s ds\right)\mathbf{1}_{\{V_T>K\}}\right] = \exp\left(a(T)+b(T)r_0\right)$$

Finally, our bond pricing formula (at t = 0) is:

$$\begin{aligned} B =& \sum_{i=1}^{2T}\frac{c}{2}\exp\left(a\left(\frac{i}{2}\right)+b\left(\frac{i}{2}\right)r\right)N\left(d_2\left(\frac{i}{2}\right)\right)+\exp\left(a(T)+b(T)r\right)N\left(d_2(T)\right) \\ &+\sum_{i=1}^{2T}\exp\left(a\left(\frac{i}{2}\right)+b\left(\frac{i}{2}\right)r\right)\left[N\left(d_3\left(\frac{i-1}{2}\right)\right)-N\left(d_2\left(\frac{i}{2}\right)\right)\right]\mathcal{R} \end{aligned} \tag{18}$$

For a zero-coupon bond where the payment contingent on default is paid at maturity, the bond price at t = 0 is:

$$B = \exp\left(a(T)+b(T)r\right)N\left(d_2(T)\right)+exp\left(a(T)+b(T)r\right)\left(1-N\left(d_2(T)\right)\right)\mathcal{R}$$

B.4 Volatility and Riskiness

Here, we use the zero-coupon bond from Section 2 to illustrate that model corporate bond volatility is not always increasing in the riskiness of the firm. Consider a safe corporate bond with low K/V. For this bond, $\partial\ln B_t/\partial\ln V_t$ approaches 0 and $\partial\ln B_t/\partial r_t$ approaches $b(\tau)$. A bond with higher K/V is riskier and has a higher sensitivity to firm value ($\partial\ln B_t/\partial\ln V_t$), but a lower sensitivity to interest rates ($\partial\ln B_t/\partial r_t$) in magnitude.

$$\left(\sigma_D^{Merton}\right)^2 = x^2\sigma_v^2 + b(\tau)^2(1-x)^2\sigma_r^2$$

for a zero-coupon bond, where $x \equiv \partial\ln B_t/\partial\ln V_t$. It can be shown that,

$$\begin{aligned} \frac{\partial\left(\sigma_D^{Merton}\right)^2}{\partial x} &= 2x\left(\sigma_v^2+b\left(\tau\right)^2\sigma_r^2\right)-2b\left(\tau\right)^2\sigma_r^2 \\ \frac{\partial\left(\sigma_D^{Merton}\right)^2}{\partial x} &< 0 \text{ if } x < \frac{b(\tau)^2\sigma_r^2}{\sigma_v^2+b(\tau)^2\sigma_r^2} \end{aligned}$$

That is, for low values of $\partial \ln B_t / \partial \ln V_t$, model variance is decreasing in $\partial \ln B_t / \partial \ln V_t$.[30] The intuition for this result is that for a Treasury bond, the sensitivity to interest rates is strongly negative, whereas for a defaultable bond, there are two effects. While a higher discount rate decreases the value of debt through a discounting channel, it also increases the value of debt as the larger risk-neutral drift for firm value decreases the likelihood of bankruptcy. The two countervailing effects tend to make a defaultable bond less sensitive to interest rates than a risk-free bond. For small values of $\partial \ln B_t / \partial \ln V_t$, this decreased sensitivity to interest rates along with an increased sensitivity to firm value actually leads to a decreased model bond volatility as the former effect dominates the latter. For a CDS, which is less sensitive to interest rates, this effect is less relevant.

C Synthetic Floating Rate Bond

C.1 Empirical Volatility

We follow Duffie and Singleton (2003) in constructing a synthetic floating rate corporate bond as a risk-free floating rate bond plus writing a CDS contract. This bond pays quarterly coupon payments equal to the prevailing 3-month interest rate at the previous coupon date (divided by 4) plus $\frac{s}{4}$, where s is the annual CDS premium. Specifically, the synthetic floating rate bond consists of three positions:

1. Risk-free floating rate bond paying quarterly

2. Inflow of $\frac{s}{4}$ each quarter if the underlying remains solvent

3. Outflow of (1 - $\mathcal{R}$) if the underlying defaults

The initial price of this synthetic bond is its face value as a risk-free floater is worth its face value at all ex-coupon dates by arbitrage arguments and the initial CDS spread is set so that the values of (2) and (3) cancel.

[30] It can similarly be shown that σ_D is decreasing in σ_v for safe firms.

To calculate returns, allow one day to elapse. Suppose now that the prevailing CDS spread is $\hat{s}$ and that the prevailing CDS spread for a (5 year - 1 day) CDS that has payments aligned with the above 5 year CDS is the same as the prevailing 5 year CDS spread. We are left to determine the changes in the value of our positions:

(1) To calculate the value of the risk-free floater, note that at the next coupon date, a coupon of $\frac{r_0}{4}$ will be paid and the ex-coupon price of the floater will be its face value. Thus, discount $1 + \frac{r_0}{4}$ at the prevailing interest rate.

(2) & (3) The value of the $\frac{s}{4}$ inflow versus the (1 - $\mathcal{R}$) outflow is the value of a stream of $\frac{s-\hat{s}}{4} = -\frac{\Delta s}{4}$. This is equal to $-\frac{\Delta s}{4}$ times the value of a risky (5 year - 1 day) annuity paying quarterly. The discount rate is the Treasury rate plus the prevailing CDS spread. Finally, add in the accrued CDS premium, properly discounted.

C.2 Model Volatility

The model bond volatility is calculated by noting the three positions that comprise the synthetic floater and applying the formulas derived in Appendix B. In particular, the value of the stream of CDS premia is:

$$\sum_{i=1}^{4T} exp\left(a\left(\frac{i}{4}\right) + b\left(\frac{i}{4}\right) r\right) N\left(d_2\left(\frac{i}{4}\right)\right) \frac{s}{4} \tag{19}$$

The value of the outflow contingent on default is:

$$\sum_{i=1}^{4T} exp\left(a\left(\frac{i}{4}\right) + b\left(\frac{i}{4}\right) r\right) \left[N\left(d_3\left(\frac{i-1}{4}\right)\right) - N\left(d_2\left(\frac{i}{4}\right)\right)\right] (1 - \mathcal{R}) \tag{20}$$

The value of a default-free floating rate bond can be calculated by noting that the value of a floating rate Treasury at ex-coupon dates is equal to its par value. Thus, we can take the value of a floating rate Treasury at t = 0.25, add the coupon payment, and discount back to t = 0. The value of a floating rate bond is then:

$$\exp\left(a\left(\frac{1}{4}\right)+b\left(\frac{1}{4}\right)r\right)\left(\frac{r_0}{4}+1\right) \tag{21}$$

The value of the synthetic floating rate bond can then be calculated as B = (19) - (20) + (21) and the sensitivities to asset value and interest rates can be calculated as $\frac{\partial \ln B}{\partial \ln V}$ and $\frac{\partial \ln B}{\partial r}$, respectively.

D Realized vs. Long-run Volatility

One potential complication in inferring asset volatility from equity volatility is that even if returns are drawn from a distribution with variance σ^2, the realized variance while an unbiased estimate of σ^2, will vary. Though our primary goal is to compare realized volatilities, the distinction between realized and true volatilities becomes important as it is the true volatility that should matter for security prices rather than the realized volatility. This affects the partial derivatives in equation (5). Here, we consider an asset volatility calculation that de-links realized and true volatilities.

In a constant asset volatility model, equity volatility varies with the leverage of a firm. Over a short horizon, leverage is typically stable enough to treat equity volatility as constant. As we will need to estimate equity volatility at a short horizon, we focus on volatilities calculated each month using daily returns. Thus, our focus will be on the CDS sample where daily returns are used. Since our focus is on CDS, which have little sensitivity to interest rates, we turn off stochastic interest rates in the model so that the interpretation of our results is more straightforward. The firm value process is

$$\frac{dV_t}{V_t} = (r-\delta)dt + \sigma_v dZ_t^Q \tag{22}$$

and the relation between realized equity volatility and asset volatility is then given by

$$\sigma_{E,t}^2 = \left(\frac{\partial \ln E_t}{\partial \ln V_t}\right)^2 \sigma_{v,t}^2 \tag{23}$$

where $\sigma_{E,t}$ and $\sigma_{v,t}$ are realized volatilities and $\partial \ln E/\partial \ln V$ relies on the long-run asset volatility, σ_v.

As log returns follow a normal distribution with variance σ_v^2, $\frac{(n-1)\sigma_{v,t}^2}{\sigma_v^2} \sim \chi_{n-1}^2$. The expectation of the realized variance $\sigma_{v,t}^2$ is equal to the true variance σ_v^2. Thus, we use

$$\sigma_v^2 = \frac{1}{N}\sum \sigma_{v,t}^2 = \frac{1}{N}\sum \frac{\sigma_{E,t}^2}{\left(\frac{\partial \ln E_t}{\partial \ln V_t}\right)^2} \tag{24}$$

where N is the number of months of data used for a firm.[31]

Using equation (24), we determine the long-run asset volatility, σ_v, and using equation (23), we infer the realized asset volatility for each period, $\sigma_{v,t}$. From these asset volatility estimates, we can then estimate model bond volatility using

$$\sigma_{D,t}^2 = \left(\frac{\partial \ln B_t}{\partial \ln V_t}\right)^2 \sigma_{v,t}^2 \tag{25}$$

A benefit of implementing the Merton model in this way is that it avoids the missing asset volatility problem described in Section 4.3.[32] The intuition is the following. Suppose we start with equation (23), but do not make a distinction between the realized asset volatility, $\sigma_{v,t}$, and the long-run asset volatility, σ_v (in the partial derivative). If the realized equity volatility, $\sigma_{E,t}$ is low, we might expect that a low σ_v would be consistent with equation (23). However, for high K/V and payout ratio firms, a low σ_v implies a large $\partial \ln E/\partial \ln V$ because of the low value of equity. The outcome is a large model equity volatility. Larger values of σ_v imply lower values of $\partial \ln E/\partial \ln V$, but the hedge ratio then scales a larger σ_v in (23).

[31] Where possible we use up to 20 years of monthly volatilities for a firm to calculate σ_v, with a minimum of 10 years of monthly volatilities used.

[32] The disadvantage is that we require a reasonable number of estimates for equity volatility to calculate long-run asset volatility in equation (24).

Thus, there may be no σ_v that can generate a low enough model equity volatility.

Here, we disentangle the realized volatility $\sigma_{v,t}$ and the long-run volatility, which is relevant for $\partial \ln E/\partial \ln V$. Equation (24) allows for low and high realized volatility periods to be averaged out over time when determining the long-run asset volatility. Thus, a few low realizations of equity volatility will not imply that the long-run asset volatility cannot be calculated. In principle, a long time-series of very low realized equity volatilities could lead to σ_v still being undefined, but we simply do not encounter this. With the long-run asset volatility fixed in the sensitivity coefficient $\partial \ln E/\partial \ln V$ in (23), a low realized equity volatility implies a low realized asset volatility, $\sigma_{v,t}$. Compared to the base calibration described in Section 2, an additional reason for not encountering the missing asset volatility problem here is that stochastic interest rates are turned off. Thus, none of the equity volatility is attributed to sensitivity to interest rates.

To implement this model, we first take firms with CDS data and limit our sample to firms that have at least 10 years of firm data.[33] We use firm-level data from 1991 to 2010 whenever possible. We then follow the methodology described above to calculate model CDS volatilities. Panel C of Table 6 provides the results to the model described in this section. The excess volatility for CDS is a positive and statistically significant 1.35%. Upon further examination, this is due to the fact that average equity variance over the last 20 years is higher than the average equity variance in our sample period. This leads to estimates of the long-run asset volatility, σ_v, that are higher than the asset volatility in the base case. In turn, this leads to greater values of bond sensitivity to firm value ($\partial \ln B/\partial \ln V$) and larger model CDS volatility.[34]

[33]We do include those firm-years that were omitted in Section 4.3 in order to illustrate that there is still excess volatility when those firm-years are included.

[34]With interest rate sensitivity turned off, there is no counteracting decrease in volatility due to a decrease in interest rate sensitivity. However, even if we had maintained stochastic interest rates in this section, the effect would be small due to the low interest rate sensitivity of CDS.

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